ESSAYS ON EQUILIBRIUM UNEMPLOYMENT, GROWTH, AND INTERNATIONAL TRADE

By

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ESSAYS ON EQUILIBRIUM UNEMPLOYMENT, GROWTH, AND INTERNATIONAL TRADE

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This dissertation consists of four chapters analyzing the issues of wage inequality and unemployment in the context of dynamic general equilibrium models of growth. The second chapter examines the interaction between long-run growth and unemployment in a closed economy setting. The third chapter extends the analysis to a two-country framework and explores the impacts of trade liberalization on wage and unemployment differentials between skilled and less-skilled labor. The fourth chapter considers the effects of minimum-wage legislation on the global economy.

The second chapter constructs a model of equilibrium unemployment by combining an endogenous growth model with a variant of search theory. An increase in the size of innovations reduces the wage of less-skilled labor relative to that of skilled labor. In addition, it raises the equilibrium rate of unemployment of less-skilled labor relative to that of skilled labor. A higher rate of technological progress has two distinct effects on the aggregate unemployment rate. First, it increases the rate of labor turnover and therefore increases the aggregate unemployment rate–

the creative destruction effect. Second, it creates R&D jobs that provide complete job security and consequently it reduces the aggregate unemployment rate–the resource reallocation effect.

The third chapter develops a model of R&D generated growth without scale effects and knowledge-based trade of higher quality products between two structurally identical countries. A global reduction in tariffs results in higher rates of innovation and growth. It also causes an increase in the expected relative earnings of skilled workers. In addition, trade liberalization increases the manufacturing unemployment rate, but has an ambiguous effect on the economy-wide unemployment rate.

The fourth chapter builds a model of knowledge-based trade between two countries, one with flexible wages (America) and another with a minimum wage for less-skilled workers (Europe). A rise in the minimum wage increases the unemployment rate in Europe. It also causes an increase in the relative wage of European skilled workers. On the other hand, the higher European minimum wage increases the proportion of industries with American leadership and reduces the relative wage of American skilled workers.

CHAPTER 1
GROWTH AND LABOR MARKETS

1.1. Introduction

Over the past two decades, the wage inequality between skilled and less-skilled workers in the United States has increased by dramatic amounts. The decline in the relative earnings of less-skilled workers coincided with an increase in their share in aggregate unemployment. The search for the causes of these developments in the U.S. labor market has dominated the recent literature in labor economics and international trade. In this dissertation, I consider the stylized changes in the U.S. labor market in the context of dynamic general equilibrium models of growth. In the second chapter, I examine the effects of technological change on wage and unemployment differentials between skilled and unskilled labor in a closed economy setting. I also investigate the question of how long-run rate of growth affects the equilibrium rate of unemployment. In the third chapter, I extend the analysis to a two-country framework and analyze the impacts of trade liberalization on labor markets. In the fourth chapter, I turn to exploring labor market rigidities and their effects on the global economy.

The rest of the present chapter briefly describes the motivation, scope, and main findings for each chapter of the dissertation.

1.2. Equilibrium Unemployment and Labor Turnover

The U.S. economy is characterized by high rates of job and worker turnover. During the interval 1973-1988, about 8% of the labor force flew in and out of unemployment in an average quarter. In the same period, 10.3 % of jobs were destroyed, and 9.1% of the jobs were created at different locations annually (Davis et al., 1996). The high volume of traffic in the labor market clearly indicates some frictional unemployment associated with the continuous restructuring of the economy. Even though considerable amount of research has been done to formalize this type of unemployment, few studies have attempted to analyze the issue in a growth framework [see Blanchard and Katz (1997) for an overview]. It is often argued that technological progress generates a continuous reshuffling of factors of production between jobs. In equilibrium, the reallocated factors become unemployed and experience a period of searching in order to find new jobs (Aghion and Howitt, 1998). To analyze unemployment driven by technological advancements and restructuring, we need a model that explicitly incorporates the growth structure of the economy and the search dynamics of the labor market. Therefore, in the second chapter, I combine an endogenous growth model with a variant of equilibrium search theory to analyze the interaction between growth and unemployment. I find that higher rate of technological progress has two opposing effects on the equilibrium rate of unemployment. First, it increases the rate of labor turnover and therefore increases the unemployment rate--the creative destruction effect. Second, it creates jobs that provide complete job-security and consequently reduces the unemployment rate--the resource reallocation effect.

The analysis of the second chapter also distinguishes between skilled and less-skilled labor in order to address the effects of growth on income distribution in the presence of equilibrium unemployment. Empirical studies report that from 1967 to 1989 the wage gap between men in the top 40 percent and bottom 10 percent of the wage distribution widened by more than 30 percentage points. During the same period, the unemployment rate of the former group increased by only 0.37 percentage points, whereas the latter increased by more than 7 percentage points (Juhn et al., 1991). The model built in chapter two predicts that technological change in the form of an increase in the innovation size may lie behind the labor market data. The higher innovation size causes the impoverishment of less-skilled workers by reducing both their wage earnings and employment rate. I find that that other exogenous shocks may also work to amplify or curtail the impacts of technological change. Along these lines, I discuss the effects of an increase in the share of skilled labor in population, an improvement in the job-matching technology, and an increase in the rate of population growth.

1.3. Knowledge-Based Trade, Unemployment, and Wages

The era of rising wage and unemployment differentials between skilled and less-skilled labor coincided with a decade of increased globalization of the world economy: the 1980's. The coincidence induced economists to investigate whether trade was responsible for the stylized changes in the U.S. labor market (Freeman, 1995; Richardson 1995). In particular, it has been argued that increased trade with the developing countries has reduced the demand for unskilled labor and taken away jobs from the U.S. economy. However, empirical studies testing the implications of the increased North-South trade in the context of standard trade theories cast doubt on their explanatory power. In a major departure from the mainstream approach, using a knowledge-based model of trade that incorporate R&D driven growth, Dinopoulos and Segerstrom (1999) argue that increased North-North trade can account for the rising wage inequality phenomena. However, their model imposes the full employment condition on the labor markets and therefore ignores the unemployment side of the picture. In a recent article, Bhagwati and Dehejia (1994) draw attention to the link between international trade and unemployment in a dynamic setting where comparative advantage shifts between the countries. They argue that increased globalization during the 1980's has contributed to the randomization of comparative advantage in different manufactured goods. The volatility in comparative advantage, in turn, has generated more labor turnover in the manufacturing sector, which intensively uses unskilled labor. Hence, the natural rate of unemployment among the unskilled workforce has risen, an effect that has also contributed to the decline in their expected relative earnings. The existing literature on unemployment and trade does not provide an adequate framework to analyze the dynamic issues raised by Bhagwati and Dehejia (1994). This literature mostly consists of static models that lack the dynamic linkages between labor markets and comparative advantage.

Building an analytical model that incorporates Bhagwati and Dehejia's notion of shifting comparative advantage and its labor market implications constitutes one motivation of the third chapter. The other motivation is to formalize the interconnection between trade, unemployment, and wages that was empirically investigated by Murphy and Welch (1992) using U.S. data. Therefore, in the third chapter, I introduce frictional unemployment to a modified version of the Dinopoulos and Segerstrom (1999) model, and explore the impacts of trade liberalization on wages and unemployment. It is a dynamic model of growth and knowledge-based trade of higher quality products between two structurally identical countries. The setting incorporates endogenous determination of innovation and skill formation. A time-consuming process of job-matching--similar to the one in the second chapter--generates unemployment. Entrepreneur firms of both countries engage in innovative activity (R&D) to discover higher quality products. Trade originates from know-how differences between the two countries; therefore, the success rate in discovering new products acts a measure of randomization in comparative advantage. Any change in trade barriers affects the profitability of R&D and alters the intensity of innovative activity. This leads to an adjustment in the success rate of entrepreneur firms and thereby establishes the linkage between trade liberalization and volatility in comparative advantage. In equilibrium, successful firms discovering the next generation product replace incumbent firms, stimulating turnover among manufacturing firms and workers. The rate of job and labor turnover in turn determines the rate of frictional unemployment.

The main result of the model is that North-North trade liberalization can account for the stylized facts of 1980's: the higher magnitudes of innovation, wage inequality, and unskilled labor unemployment. Trade liberalization works its effects through augmenting the rewards to innovation. This increases the intensity of innovative activity and accelerates the pace of technological progress. It increases the unemployment rate of unskilled labor force and diminishes the expected relative earnings of unskilled workers.

1.4. Minimum-Wage Effects on the Global Economy

The global shocks of the last two decades affected the European countries and the United States in a strikingly different fashion. In the U.S., where the labor market is flexible, the wage gap between skilled and unskilled labor has widened by tremendous amounts. In Europe, where the labor market is more rigid, the rate of unemployment has increased drastically. The most common explanation is that the relative demand for unskilled workers declined globally, and the supply response did not catch up with the demand shift. Given the institutional differences on the two sides of the Atlantic, this caused rising wage differential in the U.S. and higher unemployment in Europe [see Nickell (1997) for an overview].

There are two strands of literature on wage income inequality [see Freeman and Katz, 1995]. First, several individual country studies focus on supply and demand adjustments and institutional factors. Second, comparative labor market analyses attempt to identify common explanatory variables, exploring the developments in a set of countries. However, the implications of the proposed explanations may be quite different depending on whether the economies are separate entities or integrated through trade. Therefore, we need a unified framework that integrates countries through trade in the presence of labor market rigidities to investigate these distinct labor market developments. Brecher (1974) provides such a framework that incorporates minimum wage legislation in the context of the standard two-country Heckscher-Ohlin (henceforth H-O) model of trade.

Following Brecher's (1974) seminal work, Davis (1998, 1999), and Davis and Reeve (1997) analyzed the effects of global shocks and policy changes using a two-country H-O model of trade, calling the country with flexible wages America and the country with rigid wages Europe. Nevertheless, the analyses based on H-O models based lack the growth structure and ignore the issue of shifting trade patterns over time. In the present work, I develop a dynamic general equilibrium knowledge-based model of trade incorporating the America and Europe terminology. The setting differs fundamentally from the standard H-O model in that it explicitly incorporates the growth and R&D structure of the economy. The pattern of trade is determined by knowledge differences in producing higher quality products, unlike the H-O model where trade is driven by differences in relative factor endowments. In this model, the integrating link between the countries is the equalization of unskilled wage rates only, as opposed to the equalization of wage rates for both types of labor, as in the H-O model. Moreover, the competition to capture leadership in a fixed continuum of industries serves as an additional link between the countries. In essence, the two regions participate in a zero-sum competition, where one country's leadership position comes at the expense of the other country.

The main point of the fourth chapter is that a variety of global and local shocks can account for the stylized differences between European and U.S. labor markets. The model studies various comparative steady-state results, including adjustments in the minimum wage rate, technological change in R&D, changes in the distribution of population across countries, and adjustments in unemployment benefits. The model provides a new framework to stimulate both empirical and theoretical researchers to consider labor market rigidities in a global economy where continuous competition to innovate generates randomization in comparative advantage and determines the pattern of trade.

CHAPTER 2
A SCHUMPETERIAN MODEL OF EQUILIBRIUM UNEMPLOYMENT AND LABOR TURNOVER

2.1. Introduction

> In the long-run faster economic growth must come from a faster increase in knowledge. To the extent that the advancement of knowledge is embodied in industrial innovations it is likely to raise the job destruction rate, through automation, skill-obsolescence, and the bankruptcy associated with the process of creative destruction. In short increased growth is likely to produce an increased rate of job-turnover, and the search theories . . . imply that an increased rate of job-turnover will result in a higher natural rate of unemployment. (Aghion and Howitt, 1994, p. 477)

Davis et al. (1996) state that over a twelve-month interval, 10.3 percent of U.S. manufacturing jobs were destroyed, and 9.10 percent were created at different locations. In other words, roughly one in five jobs were reallocated annually during the interval 1973-1988. In an average quarter, about 8 percent of the labor force flows in and out of unemployment. Moreover, unemployment inflows and job destruction show a contemporaneous correlation of 0.71, and unemployment outflows and job creation exhibit a correlation of 0.16. The high rates of job and worker turnover together with the evidence on their comovement over time clearly indicate some frictional unemployment associated with the continuous restructuring of the economy.

Another distinctive feature of the U.S. labor market during the same period was the rise in wage inequality between skilled and less-skilled workers. Juhn et al. (1991) report that from 1967 to 1989 the earnings gap between men in the top 40 percent and bottom 10 percent of the wage distribution widened by more than 30 percentage points. The decline in the relative wage of less-skilled workers coincided with an increase in their share in aggregate unemployment. Figure 2-1 replicates Figure 7 of Juhn et al. (1991) which demonstrates the changes in the

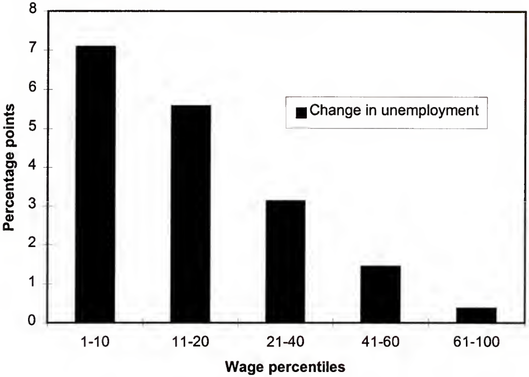

Figure 2-1: The Distribution of Long-run Changes in Unemployment by Percentiles of the Wage Distribution (1967-1989)

unemployment rates in percentage points between the economic peaks of 1967-1969 and 1987-1989 pertaining to five categories of wage percentiles. Notice that Figure 2-1 displays a negative relationship between the unemployment rate and the wage percentiles, meaning that as the skill level of worker (identified by her wage percentile) goes down, the worker is exposed to higher magnitudes of variations in unemployment. The figure reports that for the least skilled workers (falling into the 1-10 wage percentile) the unemployment rate rose by more than 7 percentage points, whereas for the most skilled workers (falling into the 61-100 percentile) the unemployment rate increased by 0.37 percentage points. Comparing the initial and final rates of unemployment within this period suggests that the unemployment rate of the former group more than doubled whereas that of the latter increased by less than 10 percent. Moreover, Juhn et al. (1991) emphasize that this distribution of unemployment is much more unequal over the long-run than over the typical cycle.[1] They state:

> . . . workers in the lowest decile of the wage distribution experienced a long term increase in unemployment that was more than three times greater than the mean sample increase, but their cyclical changes were only two times greater than the average cyclical change in unemployment. (Juhn et al. 1991, p. 103)

Economists have produced a substantial number of theoretical papers analyzing the widening wage and unemployment differential between skilled and less-skilled labor.[2] However, few studies have addressed these stylized facts within an endogenous growth framework.[3] Aghion and Howitt (henceforth AH) (1994) are the first to introduce job and worker turnover in a dynamic model of growth.[4] Nevertheless, they consider only one type of labor, and ignore the implications of growth on wage and unemployment differentials between skilled and less-skilled labor. In their setting, economic growth is fostered by the introduction of new technologies that require labor reallocation for their implementation. They identify two opposing effects of higher growth on unemployment. The *capitalization* effect leads to a fall in the unemployment rate by generating higher returns to creating jobs, which encourage more firms to create vacancies. The *creative destruction* effect causes a rise in the unemployment rate by generating a reduction in the expected duration of a job-match, which implies lower incentives to create vacancies and a higher job-separation rate. AH compare the relative strength of these two forces when the rate of growth is endogenously determined by the frequency and size of innovations. They argue that if higher growth is stimulated by parameter changes that give rise only to an increase in the frequency of innovations, the creative destruction and capitalization effects cancel each other, leaving the unemployment rate unchanged. Conversely, if higher growth is induced by an increase in the size of innovations, only the creative destruction effect operates, causing a rise in the unemployment rate.

In this chapter, I analyze the wage and unemployment differentials between skilled and less-skilled labor by combining the quality ladders growth model with a variant of equilibrium search theory. The present model distinguishes between skilled and less-skilled labor in order to address the effects of growth on income distribution in the presence of equilibrium unemployment. The model also removes the scale-effects property of early endogenous growth models by assuming that R&D becomes more difficult over time.[5] I argue that technological change in the form of an increase in innovation size can account for the decline in the relative wage of less-skilled labor and the increase in the share of less-skilled labor in aggregate unemployment.[6] Other exogenous shocks may also work to amplify or curtail these changes. In addition, the model provides an alternative to the growth and unemployment analysis of AH (1994). The model predicts that any change in endogenous growth rate—regardless of its source—influences the equilibrium rate of unemployment. More specifically, variations in exogenous parameters that affect the frequency of innovations and thereby the rate of growth also alters the rate of unemployment. This result stands in sharp contrast to the AH (1994) argument which suggests that a variation in the rate of innovations has no impact on the rate of unemployment in an endogenous growth setting. The main difference that leads to this contrast lies in the modeling of the replacement mechanism of firms. In the present model, every time an innovation takes place an existing good becomes obsolete. The innovator drives the incumbent firm out of the market after a fixed period of time is spent in searching for labor. In other words, new firms emerge strictly at the expense of old firms; hence, the flow of new jobs is equal to the flow of old jobs by construction. In the endogenous growth model of AH (1994) the emergence of new firms is governed by the arrival of innovations, whereas the closing down of firms results from increasing labor cost while price and technology are fixed. Thus, the existence of two separate mechanisms for job destruction and job creation provides an additional balanced-growth equation. When combined with the labor flow condition—which implies that the flows in and out of unemployment must equal each other—this additional equation determines the unemployment rate independent of the rate of innovation.

The model in this chapter considers a continuum of identical dynastic families. Each family is endowed with skilled and less-skilled labor, the levels of which grow at a constant exogenous rate. Each member of a family is modeled as a finitely-lived agent for a fixed period of time. The birth and death rates of population are represented by fixed parameters. The production side consists of a continuum of structurally identical industries. Firms engage in two types of activities: innovative activity (R&D) to discover higher quality products, and manufacturing activity to produce final goods. Both activities employ skilled and less-skilled labor.

Firms must engage in innovative activity to participate in sequential and stochastic R&D races. Each race is aimed at improving the quality of the product at a certain industry. There is free entry into R&D races, and workers can be hired instantly to perform innovative activity. The winner of an R&D race gains access to the technology of producing the state-of-the-art quality product. However, before starting production the successful innovator must hire manufacturing workers by going through a time-consuming search process. While the winner is engaged in recruiting workers, the incumbent firm supplies the market. Once the winner completes the job-matching process, it drives the existing firm out of the market. The workers of the incumbent firm join the economy-wide unemployment pool. Every time an innovation occurs, product obsolescence triggers this replacement mechanism of firms. Hence, at the steady-state equilibrium one observes successful innovators trying to recruit manufacturing workers, and unemployed workers trying to match with prospective employers. This endogenous labor reallocation across firms coupled with the time-consuming job-matching trigger the process of creative destruction described by Schumpeter (1942), generating frictional unemployment which can be appropriately christened *Schumpeterian unemployment*. On the other hand, at each instant in time newly-born workers that are not absorbed by R&D firms join the unemployment pool. Consequently, the birth process generates another type of frictional unemployment, which can be naturally called *biological unemployment*.

The main result of this chapter is that more rapid technological change in the form of an increase in innovation size decreases the relative wage of less-skilled workers while increasing their share in aggregate unemployment. The economic intuition for this result is as follows. The increase in the size of innovations raises the profitability of R&D. This motivates more firms to engage in innovative activity—which by assumption employs skilled labor intensively. The resulting surge in the relative demand for skilled workers puts upward pressure on their relative wage. Thus, manufacturing firms substitute less-skilled workers for skilled ones, increasing the intensity of less-skilled labor in production. In equilibrium, this requires a rise in the relative size of less-skilled workers searching for manufacturing jobs, which in turn increases their unemployment rate relative to that of skilled workers. On the other hand, the higher pace of technological progress has two effects on the aggregate unemployment rate. First is the creative destruction effect: the increase in the intensity of innovations accelerates the turnover among manufacturing firms and reduces the expected duration of a job-match, contributing positively to the aggregate unemployment rate. Second is the resource reallocation effect: the higher level of R&D activity draws resources from manufacturing to R&D and offers secure jobs for a larger portion of the labor force, contributing negatively to the aggregate unemployment rate.

The model singles out technological change as one possible explanation consistent with the stylized facts of the U.S. labor market over the last decades.[7] Nevertheless, other exogenous shocks may also work to amplify or curtail the impacts of technological change. Along these lines, the chapter discusses the effects of an increase in the share of skilled labor in population, an improvement in the job-matching technology, and an increase in the rate of population growth. [8]

This chapter is organized as follows. Section 2.2 outlines the features of the model and describes the steady-state equilibrium. Section 2.3 presents the comparative steady-state results, uncovering the intuition behind them. The last section summarizes the findings and concludes the chapter. The proofs of all propositions are contained in Appendix A.

2.2. The Model

The model combines a closed economy version of the quality-ladders growth model developed by DS (1999) and the job-matching process outlined by AH (1994).[9] The quality ladders model embodies an endogenous replacement mechanism of producers through product obsolescence. The framework incorporates R&D difficulty to remove the scale effects in the presence of population growth. I simplify the structure of DS (1999) by assuming Bertrand competition in product markets and fixing the skill distribution of workers. The setting follows AH (1994) in describing the job-matching mechanism. In addition, the model considers the implications of population growth and finitely lived individuals on job-creation and job-destruction as well as on worker flows in and out of unemployment.

2.2.1. Household Behavior

The economy consists of a representative family containing a continuum of members. Each member of a family is modeled as a finitely-lived agent for a fixed time period. The size of the representative household grows at a rate of $n = \beta - \delta$, where β and δ refer to exogenous birth and death rates, respectively. The population size at time t equals to $N(t) = N_0 e^{nt}$, where N_0 denotes the initial level of population. Each household is endowed with $L_H(t) = sN(t)$ units of skilled workers, and $L_L(t) = (1 - s)N(t)$ units of less-skilled workers; where $s \in (0, 1)$ is an exogenous parameter. The factor endowments grow at a rate of n:

$$\frac{\dot{L}_H(t)}{L_H(t)} = \frac{\dot{L}_L(t)}{L_L(t)} = \frac{\dot{N}(t)}{N(t)} = n\,. \tag{1}$$

The representative household chooses the allocation of consumption expenditure across goods at each instant in time, and the pattern of consumption over time. I assume that transfers between family members are feasible such that each member of the family realizes the same level of consumption regardless of individual earnings.[10] The family maximizes the discounted lifetime utility

$$F = \int_0^\infty N_0\, e^{-(\rho - n)t} \log Z(t)\, dt\,, \tag{2}$$

where ρ is the subjective discount rate. The function $\log Z(t)$ represents the instantaneous utility of each household member

$$\log Z(t) \equiv \int_0^1 \log\left[\, \sum_j \lambda^j\, d(j, \omega, t)\,\right] d\omega\,, \tag{3}$$

where $d(j, \omega, t)$ shows the quantity demanded of product quality j at industry ω at time t, and $\lambda > 1$ denotes the size of quality improvements (innovation size). The family allocates its per capita consumption c(t) to maximize the instantaneous utility Z(t) given prices at time t. The static maximization problem yields the unitary elastic demand function $d(t) = c(t)/p_M$, where p_M is the market price for the product in each industry that carries the lowest quality-adjusted price. The quantity demanded for all other products becomes zero. Whenever a tie occurs in the lowest quality-adjusted prices, I assume that consumers prefer the higher quality product. Given this static demand behavior, the intertemporal maximization problem of the family simplifies to maximizing

$$\int_0^{\infty} N_0 \, e^{-(\rho - n)t} \log c(t) \, dt \tag{4}$$

subject to the budget constraint $\dot{S}(t) = W(t) + r(t)S(t) - c(t)N(t)$, where S(t) denotes the financial assets of the family, W(t) is the expected wage income, and r(t) is the instantaneous rate of return. The solution to this problem yields the usual differential equation

$$\frac{\dot{c}(t)}{c(t)} = r(t) - \rho \,. \tag{5}$$

At the steady-state equilibrium consumption per capita remains constant by assumption, and equation (5) implies that the market interest rate equals the subjective discount rate $r(t) = \rho$. In the rest of the chapter, I focus on the balanced-growth path behavior and drop the time index for the variables that remain constant.

2.2.2. Product Markets

The economy is characterized by a continuum of industries indexed by $\omega \in [0, 1]$. In each industry, firms employ skilled and less-skilled labor to manufacture final goods. The manufacturing function is continuous and twice differentiable. It exhibits constant returns to scale, and the same technology of manufacturing applies to all industries, regardless of the quality of the manufactured good. The unit cost of manufacturing will be used as the numeraire. Therefore,

$$A(w_L, w_H) = 1, \tag{6}$$

where w_L and w_H stand for the wage rates of skilled and less-skilled labor, respectively. Using Shephard's lemma, one can express the skilled and less-skilled labor requirement to produce one unit of final good as $A_H = \partial A / \partial w_H$ and $A_L = \partial A / \partial w_L$, respectively.

At each instant in time, a quality leader (the firm that has access to the technique for producing the state-of-the-art quality product) competes against a follower (the firm that knows the technique of producing the one-step-below quality product) by choosing prices. With the follower charging a price equal to marginal cost (the numeraire), the leader maximizes her profit flow by charging the limit price $p_M = A\lambda = \lambda$. The follower cannot do better than break even and produces no output. Hence, the instantaneous profit flow of the leader equals

$$\pi(t) = \frac{(\lambda - 1)}{\lambda} cN(t) , \tag{7}$$

where $(\lambda - 1)$ is the profit margin per unit of output, and $cN(t)/\lambda$ is the number of units sold by the leader.

2.2.3. R&D Races

In each industry, firms compete to innovate better quality products by participating in sequential and stochastic R&D races. Competing firms hire skilled and less-skilled labor for performing R&D services. There is free entry into each R&D race, and all firms have access to the same technology of innovative activity characterized by constant returns to scale. R&D production function is continuous and twice differentiable and yields the following unit cost function

$$[B(w_L,w_H)\, X(\omega,t)] , \tag{8}$$

where $B(w_L,w_H)$ is a standard unit cost function and $X(\omega,t)$ represents the difficulty of conducting R&D services.[11] A typical firm participating in an R&D race at time t chooses the intensity of innovative activity $I_j(\omega,t)$ in order to maximize its expected discounted profits

$$\Pi(\omega,t)I_j(\omega,t)dt - B(w_L,w_H)X(\omega,t)I_j(\omega,t)dt . \tag{9}$$

Firm j enjoys the expected discounted rewards of a successful innovator $\Pi(\omega,t)$ with an instantaneous probability $I_j(\omega,t)dt$ and incurs the cost $B(w_L,w_H)X(\omega,t)I_j(\omega,t)dt$, where dt represents an infinitesimal interval of time. Free entry into R&D races implies

$$\Pi(\omega,t) = B(w_L,w_H)X(\omega,t)\,, \tag{10}$$

where the LHS can be interpreted as the price of innovation and the RHS can be viewed as the R&D difficulty adjusted marginal cost. Using Shephard's lemma, one can derive the skilled and less-skilled labor requirement per unit of R&D activity as $X(\omega,t)B_H = X(\omega,t)\partial B/\partial w_H$ and $X(\omega,t)B_L = X(\omega,t)\partial B/\partial w_L$, respectively.

The rewards to engaging in R&D are distributed independently across firms and industries. The industry-wide probability of a new product discovery is therefore given by $\Sigma_j I_j(\omega,t) = I(\omega,t)$. The arrival of innovations in each industry follows a Poisson process whose intensity is equal to $I(\omega,t)$. Note that in each industry R&D labor demands for skilled and less-skilled labor are equal to $X(\omega,t)I(\omega,t)B_H(w_L,w_H)$ and $X(\omega,t)I(\omega,t)B_L(w_L,w_H)$, respectively. In the rest of the chapter, I will call $X(\omega,t)I(\omega,t)/N(t)$ (that is, per capita R&D difficulty multiplied by the intensity of innovations) the *R&D difficulty adjusted* level of innovative activity.

To remove the scale effects from the model, I consider two different specifications of R&D difficulty $X(\omega,t)$. The first is the PEG specification

$$X(\omega,t) = \phi N(t), \qquad \phi > 0, \tag{11}$$

which captures the notion that the difficulty of performing R&D services is proportional to the size of the market. As the number of consumers grows, it becomes more difficult to introduce new products and replace old ones. With this specification, policy changes have "permanent effects on growth." The second is the TEG specification

$$\frac{\dot{X}(\omega,t)}{X(\omega,t)} = \mu I(\omega,t), \qquad \mu > 0,\ X(\omega,0) = 1, \tag{12}$$

which adopts the view that innovations that are relatively easy to discover tend to be discovered earlier. As the stock of R&D grows over time, it becomes more difficult to innovate superior products. With this specification, policy changes have "temporary effects on growth."[12]

2.2.4. Firm-Replacement Mechanism

The model generates unemployment by introducing matching frictions in the manufacturing labor market. Firms and workers can find each other instantly to engage in innovative activity, whereas both parties must go through a search process before forming a job-match to manufacture final goods.[13]

Let me now describe the creative destruction process by which successful innovators replace incumbent firms in the presence of time-consuming job matching. The winner of an R&D race gains access to the technology of producing the state-of-the-art quality product in an industry at time t. To recruit manufacturing workers, the winner creates job positions instantly.[14] When successfully matched, a *job position* can produce one unit of output. Each job position consists of *vacancies* designed for skilled and less-skilled labor, the optimal levels of which are given by A_L and A_H, respectively. Let y represent the parameter that shows the search time to form a successful *job match* for each job position.[15,16]

During the search period (t, t + y) the winner firm can produce no output until it has terminated the job-matching process. Therefore, the incumbent firm supplies the market. At time (t + y) the emerging leader completes the initial job-matching process and replaces the incumbent firm. The workers of the incumbent firm join the economy-wide unemployment pool. Further innovation in the industry triggers the same mechanism of replacement, which requires the new innovator to go through a search of duration y. This in turn gives the previous innovator the opportunity to supply the market for a period of y. Consequently, the existence of matching frictions does not alter the expected duration of temporary monopoly profits (i.e., the expected lifetime of a product). The search process only delays the realization of initial profits for a time interval of length y.

In addition to job positions aimed at replacing the incumbent, the winner firm creates extra jobs starting from time t in order to satisfy the expanding consumer demand. This forward-looking job creation scheme enables the leader to enjoy instantaneous profits growing at the rate of population growth. The expansionary job creation stops when a new product discovery takes place, since it signals the incumbent firm that it will be replaced after a time interval length of y.

Let η denote the random variable that represents the interarrival time period between innovations. The arrival of innovations follows a stochastic Poisson process; thus, η is distributed exponentially over an infinite horizon with parameter I. The intensity of innovations I is endogenously determined. The expected discounted profits of a successful innovator is given by

$$\Pi(t) = e^{-\rho y}\{ \int_0^\infty \; Ie^{-I\eta}[\int_0^\eta \pi(t)\, e^{-(\rho - n)s}\, ds]\, d\eta\}, \tag{13.a}$$

$$= e^{-\rho y} \frac{\pi(t)}{(\rho + I - n)}. \tag{13.b}$$

The bracketed expression in equation (13.a) represents the discounted instantaneous profit flow of a quality leader realized for the duration η. Discounting the expression in parenthesis in equation (13.a) at the prevailing interest rate ρ for a period of y accounts for the initial search time of the firm during which no output can be produced by the innovator.

2.2.5. The Job-Matching Process

I follow AH (1994) in formalizing the job-matching in manufacturing. Let subscript $i = L$ represent less-skilled workers, and $i = H$ stand for skilled workers. Assume that for type i workers there is a matching function $m(V_i(t),L_{iS}(t))$ that determines the aggregate flow of completed job matches workers as an increasing function of the aggregate level of vacancies $V_i(t)$ and the number of searching workers $L_{is}(t)$, where subscript s represents searching workers. The matching function is concave and homogenous of degree one in its arguments with positive marginal products. Note that the matching process treats variables referring to skilled and less-skilled labor separately. However, without loss of generality, I assume that identical matching technology applies to both types of labor. Dividing $m(V_i(t),L_{is}(t))$ by $L_{is}(t)$ yields the aggregate job-finding rate $p(v_i(t)) = m(v_i(t),1)$, where $v_i(t) = V_i(t)/L_{iS}(t)$ stands for the vacancy rate. Similarly, dividing $m(V_i(t),L_{is}(t))$ by $V_i(t)$ gives the aggregate recruiting success rate, $q(v_i(t)) = m(1,1/v_i(t))$. The transition rates $p(v_i(t))$ and $q(v_i(t))$ must satisfy $q(v_i(t))V_i(t) = p(v_i(t))L_{iS}(t) = m(V_i(t),L_{iS}(t))$. Moreover, assume that $q(0) = p(\infty) = \infty$, $q(\infty) = p(0) = 0$, and $p(v_i) > 0$ for all v_i.

2.2.6. Labor Market Equilibrium

Labor market equilibrium for each type of labor requires its supply to equal its demand plus the number of unemployed workers. The supply of labor is given by $L_H = sN(t)$ and $L_L = (1 - s)N(t)$ for skilled and less-skilled labor, respectively. The demand for labor comes from manufacturing and R&D. Given that the economy is comprised of structurally identical industries with a measure of one, in a symmetric equilibrium the industry-wide and the economy-wide intensity of effective R&D is equal to $I(\omega,t)$. Thus, the aggregate demand for type i labor by R&D firms is given by $B_i(w_L,w_H)xN(t)I$, where $x = X(t)/N(t)$ stands for per capita R&D difficulty. Since $I(\omega,t)$ and $x(\omega,t)$ remain constant in the steady-state equilibrium, the time and industry indexes are omitted for notational simplicity and clarity. With a measure one of industries, the economy-wide demand for manufactured goods is equal to $M(t) = cN(t)/\lambda$. Hence, the aggregate derived demand for type i labor by manufacturing firms is given by $A_i(w_L,w_H)M(t)$. To analyze the level of unemployed workers, let me define the unemployment rate of searching type i labor as $u_{iS} = U_i/L_{iS}$, where U_i stands for the number of unemployed type i workers and L_{iS} represents the size of the searching type-i labor force. Following AH (1994), I assume that the *entire* group of workers that are not absorbed by R&D firms constitute the searching labor force of the economy.[17] Therefore, the searching skilled and less-skilled labor forces are respectively

$$L_{HS} = [s - B_H(w_L, w_H)xI]N(t), \tag{14}$$

$$L_{LS} = [1 - s - B_L(w_L, w_H)xI]N(t)\,. \tag{15}$$

Using the above equations, one can derive the labor market equilibrium conditions for skilled and less-skilled labor, respectively[18]

$$(1 - u_H)[s - B_H(w_L,w_H)xI]N(t) = A_H M(t), \tag{16}$$

$$(1 - u_L)[1 - s - B_L(w_L,w_H)xI]N(t) = A_L M(t)\,. \tag{17}$$

The LHS of equation (16) shows the supply of skilled labor available for manufacturing, whereas the RHS represents the demand for skilled labor by manufacturing firms. A similar interpretation holds for equation (17).

2.2.7. Steady-State Vacancy and Labor Flows

This section derives the aggregate vacancy and labor flows into the economy generated by arrival of new products and biological turnover of workers. I start by investigating the job flows of the economy. Each job position consists of vacancies targeting skilled and less-skilled labor separately. Following the discussion in section 2.2.4, I classify job positions into two categories: job openings by winner firms aimed at replacing incumbent firms, and job openings by leader firms aimed at satisfying expanding consumer demand.

At time t new leaders emerge in *a proportion Idt of industries* and create job positions. Each job position must wait for a period of y before forming a successful job match. During the search period the demand for the product of the emerging leader will expand at the rate of population growth. Consequently, each winner creates $A_iM(t + y)$ vacancies for i = H, L to satisfy the expected product demand at time (t + y). When these vacancies are successfully matched, the winner replaces the incumbent producer. In addition, at time t all firms with leading technologies calculate the expansion in demand (due to population growth) and the separation in job-matches (due to death of employed workers) that will take place at time (t + y). The leaders must create vacancies at time t to counterbalance these distortions. Therefore, in *all industries* each leader firm opens up $(\beta - \delta)A_iM(t + y)dt$ vacancies to keep up with demand expansion and $\delta A_i M(t + y)dt$ vacancies to compensate for job separations, for i = H, L. Thus, the steady-state flow of vacancies is

$$\dot{V}_i\, dt = (I + \beta)\, A_i M(t + y)dt - p(v_i)L_{iS}(t)dt \qquad \text{for } i = H, L. \qquad (18)$$

The first expression in equation (18) refers to the total inflow of vacancies (by emerging leaders and currently operating firms), and the second term stands for the flow of successful job-matches. The vacancy rate will remain fixed at the steady-state equilibrium. Using equations (14) through (17), this yields the following balanced-growth relationship[19]

$$\frac{\dot{V}_i}{V_i} = \frac{(I + \beta)(1 - u_{iS})e^{ny} - p(v_i)}{v_i} = (\beta - \delta), \qquad \text{for } i = H, L, \qquad (19)$$

which equates the growth rate of vacancies to the growth rate of population

Next, I investigate the labor flows in and out of unemployment. Every time an innovation takes place, an existing product becomes obsolete. The incumbent firm shuts down and all its workers become unemployed. In the continuum of industries with measure one, the aggregate number of filled positions in manufacturing is $A_i M(t)$ for i = H, L. The workers in these jobs are laid off and join the unemployment pool with an instantaneous probability Idt. In addition, population growth alters the flow of unemployed workers at each instant of time. A newly-born type i worker who cannot find employment in R&D joins the searching type i labor force as an unemployed worker. Thus, the birth of type i workers stimulates an expansion in the unemployment pool given by βL_{iS}. On the other hand, the death of jobless type i workers generates a contraction in unemployment pool measured by δU_i. Thus, the steady-state flow of unemployed workers is

$$\dot{U}_i\, dt = IA_i M(t)dt + (\beta - \delta u_{iS})L_{iS}dt - p(v_i)L_{iS}(t)dt, \qquad \text{for } i = H, L, \qquad (20)$$

The first expression in equation (20) represents the flow of displaced workers due to technological advancements.[20] The second expression captures the net flow of workers generated by the birth and death processes (the biological flow). Finally, the third expression stands for the flow of successful job matches. The unemployment rate of searching workers remains constant at the steady-state equilibrium. Using equations (14) through (17), this implies the following balanced-growth condition[21]

$$\frac{\dot{U}_i}{U_i} = \frac{I(1-u_{iS})+\beta-\delta u_{iS}-p(v_i)}{u_{iS}} = (\beta-\delta), \qquad \text{for } i = H, L, \tag{21}$$

which equates the growth rate of unemployed type i workers to the growth rate of population.

2.2.8. Steady-State Equilibrium

To characterize the steady-state equilibrium, I first focus on the determination of the vacancy rate v_i for i = H, L. With superscript (*) referring to the steady-state equilibrium values, equations (19) and (21) can be solved for $v_i^* > 0$ [see Appendix A]. Note that v_i^* depends only on β, δ and the specification of matching technology. Since the parameters pertaining to population growth and matching function are identical for both types of labor, the vacancy rates are also identical, that is $v^* = v_L = v_H$. To complete the analysis given v^*, I will utilize the zero profit condition in R&D, the labor market equilibrium conditions, and a specification for R&D difficulty. Substituting equation (13.b) into equation (10), using equation (7), equation (17) and equation (21) with $M(t) = cN(t)/\lambda$, I obtain the "free-entry in R&D condition"

$$xB(w_L, w_H) = \frac{e^{-\rho y}p(v^*)(\lambda-1)[1-s-B_L(w_L,w_H)xI]}{(I+\beta)A_L(w_L,w_H)(\rho+I-n)}, \qquad \textbf{FEC} \quad (22)$$

which simply states that R&D difficulty adjusted marginal cost of R&D must be equal to the marginal return. Taking the ratio of equation (17) to equation (18) with $u_S^* = u_{SL}^* = u_{SH}^*$, I derive the "labor market equilibrium condition"[22]

$$\frac{(1-s-B_L(w_L,w_H)xI)}{(s-B_H(w_L,w_H)xI)} = \frac{A_L(w_L,w_H)}{A_H(w_L,w_H)}, \qquad \textbf{LMC} \quad (23)$$

where the LHS is the relative size of searching less-skilled labor force L_{LS}/L_{HS}, and the RHS is the intensity of less-skilled labor in manufacturing (i.e., the less-skilled skilled labor ratio in manufacturing). Note that equation (6) implicitly defines w_H as a function of w_L; thus, equations (22) and (23) define a system of two equations in three unknowns I, w_L, and x. The specification for R&D difficulty, being either equation (11) or equation (12), provides the third equation.

Proposition 1: *Under the assumptions below, a unique steady-state equilibrium exists in which the level of innovative active I; per capita R&D difficulty x; consumption per capita c; the vacancy rate v; the unemployment rate* u_S*; and the wage rates of skilled and less-skilled labor* w_L *and* w_H *attain strictly positive values and remain constant over time.*

Assumptions:

A.1. R&D is skilled labor-intensive relative to manufacturing $(B_H/B_L) > (A_H/A_L)$,

A.2. The birth rate is greater than the job-finding rate at the steady-state equilibrium $\beta > p(v^*)$,

A.3. In the PEG model, the innovation size λ *is sufficiently high, the discount rate* ρ*, and the R&D difficulty parameter* ϕ *are sufficiently low; in the TEG model as* $w_L \rightarrow \infty, \lim A_L B \neq \infty$.

Proof. See Appendix A.

Assumption 1 imposes the empirically relevant restriction on the production functions, which entails that R&D is skilled labor intensive relative to manufacturing. Assumption 2 states a sufficient condition for the unemployment rate of searching workers u_S to be positive [see Section 2.2.11]. Assumption 3 presents the sufficient conditions that guarantee the existence of equilibrium [see Appendix A for details].

The PEG specification implies that x = k [see equation (11)]; therefore equations (22) and (23) can be solved for the two endogenous variables I and w_L. Figure 2-2 illustrates the equilibrium by the unique intersection of FEC and LMC curves. The vertical axis designates the wage rate of less-skilled workers w_L, and the horizontal axis designates the rate of technological change I. The FEC curve establishes a positive relationship between I and w_L. For a given level of I, an increase in w_L raises the profitability of R&D activity. As a result, more firms enter into R&D races until the expected profits are driven back to zero, an adjustment which requires an

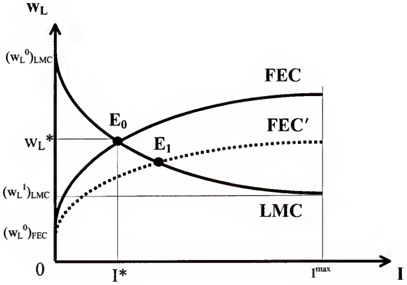

Figure 2-2: The Effects of an Increase in Innovation Size λ (the PEG Model)

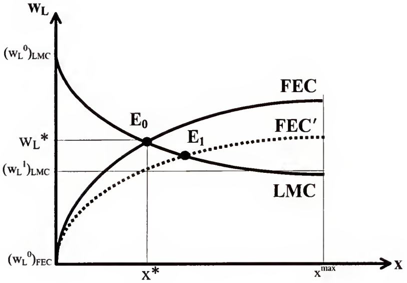

Figure 2-3: The Effects of an Increase in Innovation Size λ (the TEG Model)

increase in I. The LMC curve, on the other hand, defines a negative relationship between I and w_L. For a fixed level of I, an increase in w_L reduces the intensity of less-skilled labor employed in manufacturing A_L/A_H and increases the relative size of searching less-skilled labor force L_{LS}/L_{HS}. To maintain equilibrium, the ratio L_{LS}/L_{HS} decreases through a reduction in I. On the LMC curve $(w_L^0)_{LMC}$ represents the wage level that would prevail when the economy completely specializes in manufacturing (i.e., $I = 0$), and $(w_L^1)_{LMC}$ designates the wage level that would prevail when the economy completely specializes in R&D (i.e., $I = I^{max}$).[23]

The TEG specification implies that $I = n/\mu$, since R&D difficulty grows at a constant rate of n at the steady-state equilibrium (See Equation (12)). Thus, equations (22) and (23) can be solved for the two endogenous variables x and w_L. Figure 2-3 displays the equilibrium by the unique intersection of FEC and LMC curves. The vertical axis measures the wage rate of less-skilled workers w_L, and the horizontal axis measures the relative R&D difficulty x. The FEC curve defines w_L as an increasing function of x. For a given level of x, an increase in w_L raises the rewards of innovating. This induces more firms to engage in R&D. However, the intensity of R&D is fixed by $I = n/\mu$. To maintain equilibrium, the marginal cost of R&D must attain a higher level through an increase in x. The LMC curve, on the other hand, identifies w_L as a decreasing function of x . For a given level of x, an increase in w_L reduces A_L/A_H and raises L_{LS}/L_{HS}. To restore equilibrium, the L_{LS}/L_{HS} ratio decreases through a reduction in x. On the LMC curve w_L^0 and w_L^1 have the same interpretations as in the case of the PEG model above, since x and I enter equation (23) symmetrically.

2.2.9. Long-Run Growth

The steady-state growth rate of the economy is derived by calculating the growth rate of a representative individual's instantaneous utility. Substituting $d = c(t)/\lambda$ into equation (3), I obtain $\log Z(t) = \log c(t) - \log\lambda + \int_1^0 \log\lambda^{j(\omega,t)} d\omega$, where $j(\omega,t)$ refers to the quality level of the highest quality product in industry ω at time t. The only term that is time dependent in this expression is the integral term whose expected value equals tIlogλ. Hence, at the steady-state equilibrium, the

Schumpeterian growth rate of the economy is given by

$$g = \frac{\dot{Z}(t)}{Z(t)} = I\log\lambda\,, \tag{24}$$

which states that the rate of growth increases with the intensity of effective R&D and the size of innovations. The constant level of I in the presence of population growth guarantees that the growth rate of the economy is free of scale effects.

2.2.10. Steady-State Unemployment

The equilibrium rate of unemployment of searching workers can be calculated by substituting v* and I* into equation (21):

$$u_S{}^* = 1 - \frac{p(v^*)}{(I^*+\beta)}. \tag{25}$$

Note that $u_S{}^* = u_{LS} = u_{HS}$ must hold, since $p(v^*)/(I^* + \beta)$ is identical for both types of labor. The necessary condition for a positive level of $u_S{}^*$ is that $p(v^*) < (I^* + \beta)$.[24] This condition suggests that two mechanisms give rise to equilibrium unemployment. First, the creative destruction process (the rate of which is measured by I) generates *Schumpeterian unemployment* by stimulating turnover among manufacturing firms that results in labor reallocation. Second, the birth process (the rate of which is measured by β) generates *biological unemployment* by producing a continuous flow of individuals who join the labor force as unemployed workers. Holding other parameters constant, an increase in the rate of innovation or the rate of birth contributes positively to the rate of unemployment.

The model so far has considered the unemployment rate of searching workers to characterize the steady-state equilibrium in its simplest form. However, focusing on $u_S{}^*$ alone will not suffice if one attempts to investigate the relative unemployment rate of less-skilled workers or the aggregate unemployment rate of the economy.[25] To analyze these alternative measures, let me start by defining the relative unemployment rate of less-skilled workers $u_R = U_L(t)/U_H(t)$ as the number of unemployed less-skilled workers divided by the number of unemployed skilled workers. At the steady-state equilibrium, using $U_i = u_S{}^*L_{iS}$ for i = H, L, and equations (16) and (17), it follows that

$$u_R{}^* = \left(\frac{A_L}{A_H}\right)^* . \tag{26}$$

Hence, an exogenous shock that increases the intensity of less-skilled labor in manufacturing boosts the unemployment differential between skilled and less-skilled labor.[26] The intuition is that a higher level of A_L/A_H can only be maintained if the relative number of less-skilled workers searching for manufacturing jobs increases. This increases the relative exposure of less-skilled workers to unemployment.

Next, I introduce the aggregate unemployment rate $u_A = (U_L(t) + U_H(t))/N(t)$, which is defined as the total number of unemployed workers divided by the size of population. Using $U_i = u_S{}^*L_{iS}$ for i = H, L with equations (14) and (15), it follows that

$$u_A = u_S{}^*[1 - x^*I^*(B_L{}^* + B_H{}^*)] . \tag{27}$$

The aggregate unemployment rate consists of two components: the unemployment rate of searching workers and the share of searching workers in the population. Holding other parameters constant, an increase in the intensity of R&D I^* has two effects on the aggregate unemployment rate u_A. The first is the *creative destruction* effect (identified by AH (1994)). The higher innovation rate raises the rate at which products replace each other, and thereby accelerates the turnover among manufacturing jobs. This reduces the expected duration of a job-match and puts upward pressure on the aggregate unemployment rate by increasing its first component $u_S{}^*$. The second is the *resource reallocation* effect. The increase in the intensity of innovative activity requires resources to move from manufacturing to R&D. Thus, a higher fraction of the labor force can be employed by R&D firms with complete job security. This puts downward pressure on the aggregate unemployment rate by reducing its second component $[1 - x^*I^*(B_L^* + B_H^*)]$.

2.3. Comparative Steady-State Analysis

2.3.1. Changes in the Size of Innovations

Proposition 2: *An exogenous increase in the relative price of innovation implied by an increase innovation size* λ *(demand-driven technological change)*

(i) *reduces the wage of less-skilled labor* w_L, *and increases the wage of skilled labor* w_H,

(ii) *increases the R&D difficulty adjusted level of innovative activity* xI *(for the PEG model through an increase in I, for the TEG model through an increase in x),*

(iii) *increases the long-run relative unemployment rate of less-skilled labor* $[u_R = U_L/U_H]$,

(iv) *exerts an ambiguous impact on the aggregate unemployment rate* $[u_A = (U_L + U_H)/N]$ *for the PEG model, decreases the aggregate unemployment rate for the TEG model,*

(v) *increases the rate of long-run growth (permanently for the PEG model, temporarily for the TEG model).*

Proof. See Appendix A.

Figures 2-2 and 2-3 display the effects on an increase in the size of innovations on w_L and I for the PEG model, and on w_L and x for the TEG model, respectively. The higher level of λ increases the rewards of innovation, inducing more firms to engage in R&D. Hence, the R&D difficulty adjusted level of innovative activity xI must rise (for the TEG model through an increase in I, for the TEG model through an increase in x). The increased level of xI stimulates a rise in the relative demand for skilled labor (since$(A_L/A_H) > (B_L/B_H)$). The higher demand puts upward pressure on the wage of skilled workers w_H, and downward pressure on the wage of less-skilled workers w_L. At the new equilibrium xI increases and w_L decreases.

The reduction in the relative wage of less-skilled labor motivates manufacturing firms to substitute less-skilled labor for skilled labor. To maintain the increase in the intensity of less-skilled labor in manufacturing A_L/A_H, relatively more less-skilled workers must search for manufacturing jobs and expose themselves to unemployment. Thus, the relative unemployment rate of less-skilled workers u_R must rise.

The aggregate unemployment rate, on the other hand, is subject to different forces depending on the R&D difficulty specification. In the PEG model, two effects are observed. First, the higher rate of innovations triggers the creative destruction effect. The increase in I speeds up the labor turnover in manufacturing and reduces the duration of a job-match, contributing positively to u_A. Second, the increased R&D activity stimulates the resource reallocation effect. The higher level of I draws resources from manufacturing to R&D and provides secure employment for a larger fraction of the labor force, contributing negatively to u_A. The reduced w_L may amplify or curtail the resource reallocation effect without changing its direction.[27] The net impact of the above mentioned effects on u_A is ambiguous. Next, I consider the TEG model. Since the rate of technological progress remains constant, the creative destruction effect vanishes. The higher level of difficulty adjusted R&D through an increase in x now triggers the resource reallocation effect. The reduced w_L does not alter the direction of this change. As a result, the impact of higher x on u_A is negative.

2.3.2. Changes in the Skill Distribution of Population

Proposition 3: *Under the sufficient conditions* $(dB_H + dB_L)/dw_L < 0$ $(dA_H + dA_L)/dw_L < 0$, *an exogenous increase in the relative endowment of skilled workers* $s/(1 - s)$ *(i.e., an increase in the proportion of skilled workers s)*

(i) *increases the wage of less-skilled labor* w_L, *and decreases the wage of skilled labor* w_H,

(ii) *increases the R&D difficulty adjusted level of innovative activity xI (through an increase in I for the PEG model, through an increase in x for the TEG model),*

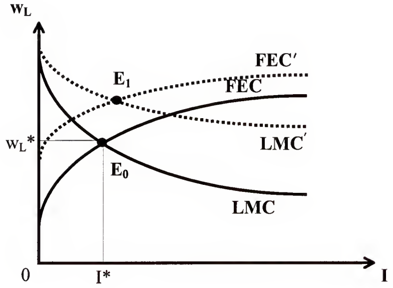

Figure 2-4: The Effects of an Increase in Share of Skilled Labor s (the PEG Model)

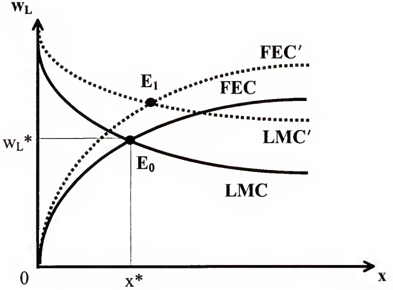

Figure 2-5: The Effects of an Increase in Share of Skilled Labor s (the TEG Model)

(iii) *decreases the relative unemployment rate of less-skilled workers* $[u_R = U_L/U_H]$,

(iv) *exerts an ambiguous impact on the aggregate unemployment rate* $[u_A = (U_L + U_H)/N]$,

(v) *increases the rate of long-run growth (permanently for the PEG model, temporarily for the TEG model).*

Proof. See Appendix A.

Figures 2-4 and 2-5 display the effects of an increase in the share of skilled labor in population for the PEG and TEG models, respectively. The FEC equation implies that an increase in s reduces the profitability of R&D activity. Consequently, firms exit from R&D races. This decreases the level of difficulty adjusted R&D xI (through a decrease in I in the PEG model, through a decrease in x in the TEG model). The resulting reduction in the relative demand for skilled labor puts downward pressure on w_H and upward pressure on w_L. On the other hand, a higher level of s distorts the LMC equation by reducing the relative size of less-skilled searching workers L_{LS}/L_{HS}. To maintain equilibrium, the difficulty adjusted level of R&D xI and wage of less-skilled labor w_L must increase. Under the assumption stated in Proposition 3, at the new equilibrium w_L and Ix both attain higher values.[28]

The relative unemployment rate of less-skilled workers u_R decreases, because the increase in the relative wage of less-skilled labor reduces the intensity of less-skilled labor in manufacturing. To analyze variations in the aggregate unemployment rate, I start by considering the PEG model where u_A is subject to two effects. First, the higher rate of innovation triggers the creative destruction effect and contributes positively to u_A. Second, the increased level of difficulty-adjusted innovative activity stimulates the resource reallocation effect. However, the increase in w_L mitigates this effect by reducing the size of R&D employment (under the assumption of Proposition 3). Therefore, the resource reallocation effect points to an indeterminate direction. The net adjustment in u_A depends on the parameters of the model.

Next, I investigate the TEG model. Since the rate of innovations remains fixed, the creative destruction effect vanishes. The change in u_A is governed solely by the resource reallocation effect that is subject to the same competing forces described in the PEG model. Thus, the net change in u_A is ambiguous.

2.3.3. Changes in Matching Technology and the Rate of Population Growth

I now investigate the effects of an improvement in the matching technology and an increase in rate of population growth. Suppose that the aggregate matching function takes the Cobb-Douglas form $m(V_i, L_{iS}) = GV_i^{\delta}L_{iS}^{1-\delta}$; where a variation in G represents neutral technical change, δ and $(1 - \delta)$ determine the effectiveness of vacancies and searching workers, respectively. The equilibrium flow identity implies that $p(v_i) = Gv_i^{\delta}$ and $q(v_i) = Gv_i^{\delta-1}$. Hence, a more efficient matching technology implied by a higher G contributes positively to the job-finding rate and vacancy-filling rate. Recall that equations (19) and (21) determine the equilibrium level of v*. An improvement in matching technology leads to an increase in v*. The higher level of v* enables more workers to find jobs in manufacturing and increases the rewards for innovating. Consequently, the effects of an improvement in matching technology are almost identical to those of an increase in innovation size, under both versions of the model. The only difference is that with improved matching the higher job-finding rate generates an additional influence on the aggregate unemployment rate that mitigates the creative destruction effect.

Next, I explore the effects of an increase in rate of population growth $n = \beta - \delta$ induced by an increase in the birth rate (i.e., $d\beta > 0$ and $d\delta = 0$). I consider only the TEG model, where a higher population growth rate unambiguously stimulates a rise in the innovation rate (Note that $I = n/\phi$) . An increase in n shifts the FEC curve through five direct effects, leaving the LMC curve unchanged. First, the higher rate of birth contributes positively to biological unemployment by augmenting the flow of newly-born workers. Second, the higher innovation rate adds to Schumpeterian unemployment by increasing the turnover rate of manufacturing jobs. Third, the higher rate of innovation requires an increase in R&D employment, which draws resources from manufacturing. Fourth, the higher rate of innovation increases the probability of the firm's being replaced. Each effect above negatively contributes to the rewards from innovating. Nevertheless, the fifth effect turns out to be a positive one, which operates through increasing the growth rate of monopoly profits. In addition, the higher n shifts the FEC curve indirectly by generating an ambiguous change in v*. To sum up, a variation in population the growth rate has an ambiguous effect on the long-run unemployment.

The positive effect of higher growth on the profitability of R&D is, indeed, quite similar to the capitalization effect identified by AH (1994). In their model AH argue that higher growth increases the capitalized earnings of the firm. The increased returns to creating jobs increases the vacancy rate, thereby reducing the rate of unemployment. In the TEG version of the present model, the higher capitalized earnings motivate more firms to enter into R&D races. This entails a rise in the per capita difficulty of R&D x, which in turn stimulates the resource reallocation effect and therefore leads to a fall in the aggregate unemployment rate. Thus, the TEG version of the model resurrects the capitalization effect; however, the mechanism that leads to this result fundamentally differs from that of AH (1994). The reduction in the unemployment rate does not materialize through an adjustment in the vacancy rate in the present model. The reason is that the higher innovation rate (induced by a rise in n) augments the rate of increase in u_S, and the rate of increase in v in the same proportion; thus, the equilibrium job-matching rate and therefore the vacancy rate do not need to change to maintain the steady-state equilibrium.[29]

2.4. Conclusion

In this chapter, I have developed a model of long-run equilibrium unemployment by introducing labor market matching frictions to the quality-ladders growth model. The model generates unemployment through an endogenous hiring and firing mechanism induced by product obsolescence. The creative destruction process coupled with a time-consuming search requirement to form a job-match generates Schumpeterian unemployment. On the other hand, the birth process generates biological unemployment by producing a continuous flow of labor into the unemployment pool.

The model explores the wage and unemployment differentials between skilled and less-skilled labor. I find that an exogenous increase in innovation size reduces the relative wage of less-skilled workers while increasing their relative unemployment. An increase in the share of skilled labor in population has the opposite effects on these variables.

The discussion of the chapter on unemployment and growth provides an alternative to the analysis of AH (1994). I find that any change in the endogenous growth rate—regardless of its source—influences unemployment. Thus, changes in exogenous parameters that affect the rate of innovations, and thereby the rate of growth, also exert an influence on the rate of unemployment. This result stands in sharp contrast to the argument of AH (1994), which suggests that a variation in the rate of innovations has no impact on the rate of unemployment in an endogenous growth setting.

2.5. Notes

[1] Alternatively, the OECD Jobs Study (1994) analyzes the unemployment rates for the bottom and top quartiles of the labor force ranked by education from the lowest to the highest level of attainment. The report points out that between 1970 and 1989 the unemployment rate in the U.S. for men within the bottom quartile increased from 4.0 to 8.1 percent, whereas the unemployment rate for men within the top quartile increased from 1.7 percent to 2.3 percent.

[2] See Johnson (1997), and Kosters (1994) for overviews on wage inequality. See Blanchard and Katz (1997), and Rogerson (1997) for surveys on the natural rate of unemployment.

[3] Bean and Pissarides (1993) analyze the relationship between growth and unemployment using a standard overlapping generations framework that incorporates matching frictions in the labor market. Cahuc and Michel (1996) explore the implications of minimum wage legislation in an overlapping generations model that distinguishes between skilled and less-skilled labor.

[4] In a recent book, Aghion and Howitt (1998) consider various extensions of their 1994 study. Starting from a simple model of exogenous growth and unemployment, they introduce intersectoral complementarities, endogenous growth, learning by doing, and stochastic matching.

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[5] Earlier models of endogenous growth that exhibit the scale-effects property, which implies explosive steady-state growth in the presence of population growth, include Aghion and Howitt (1992), Grossman and Helpman (1991a), Romer (1990), and Segerstrom et al. (1990). Dinopoulos and Thompson (1999a) provide a recent overview of scale effects in the neo-Schumpeterian models of growth.

[6] In addition, the higher innovation size stimulates a rise in the frequency of innovations and motivates resources to move from manufacturing to R&D. This result is also consistent with the empirical evidence that the number of patent applications exhibited an upward trend during 1970's and 1980's [Grilliches (1990)] and that R&D expenditures as a fraction of manufacturing shipments increased from 2.4 percent in 1973 to 3.9 percent in 1987 [Berman et al. (1994)].

[7] Lipsey (1994) and Kortum (1997) argue that the value of innovations have increased due to broader patent protection and internationalization of U.S. firms. Kortum (1993) interprets the increased shipments of U.S. manufacturing products between 1959-83 as a factor that contributes positively to the value of innovations. In the present model, these demand driven changes in the value of innovations can be captured by an increase in the size of innovations. Using patent renewal data, Pakes and Schankerman (1986) estimate the value of patents for three European countries and conclude that the average quality of patents had increased over time. Using U.S. data, Thompson (1996) provides contrary evidence by estimating the stock market valuation of a patent.

[8] Using a Cobb-Douglas production function for manufacturing, and assuming a Ricardian production for R&D that employs only skilled labor, I examined the effects of skilled-labor biased technological change in manufacturing (TC-M), and skilled labor-saving technological change in R&D (TC-R). The results imply that TC-M reduces both the rate of innovation and the unemployment rate of less-skilled labor. Thus, the changes generated by TC-M are inconsistent with the U.S. data. On the other hand, I find that TC-R increases both the rate of innovation and the unemployment rate of less-skilled labor. It also causes a rise in wage inequality if the relative wage of less-skilled labor is sufficiently small. Hence, the predictions of TC-R are consistent with the stylized facts. The TC-R explanation is also compatible with the empirical and theoretical results of Slaughter and Haskel (1998). They argue that if technological change is in the skilled biased sector, then it is more likely to increase the wage inequality.

[9] See Pissarides (1985), Blanchard and Diamond (1989), and Mortensen and Pissarides (1994) for models that incorporate job-matching and search in different settings.

[10] The feasibility of transfers between family members simplifies the dynamic optimization problem by avoiding any truncation in individual income. One can also assert that the intrafamily transfers perfectly insure each member of the household against any income shock.

[11] The underlying production function is $I_j(\omega,t) = F(L_{Hj},L_{Lj})/X(\omega,t)$, where L_{Hj} stands for skilled labor and L_{Lj} stands for less-skilled labor employed by firm j.

[12] The TEG specification is formalized by Segerstrom (1998), and the PEG specification is proposed by Dinopoulos and Thompson (1996). Time series evidence based on U.S. annual data

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over the period 1950-90 provided by Dinopoulos and Thompson (1999b) suggests that one cannot reject one specification in favor of other.

[13] This dual treatment of labor markets is consistent with empirical evidence. Saint-Paul (1996) points out that jobs can be classified into two categories: primary jobs (characterized by high wages and low turnover), and secondary jobs (characterized by low wages and high turnover). A similar structure is followed in Acemoglu (1998), where jobs are classified as high quality jobs targeting skilled labor, and low quality jobs designed for less-skilled labor. In the present model, R&D activity creates primary jobs and manufacturing activity creates secondary jobs. The former activity employs skilled labor intensively compared to the latter. To simplify the exposition, I assume that job matching is instantaneous in primary jobs (R&D) and time consuming in secondary jobs (manufacturing). See Davidson et al. (1988) for a model that incorporates search in one production activity in a standard general equilibrium framework.

[14] I assume that job positions can be created and maintained without any cost. However, as in the search and matching literature vacancies must represent real jobs [see Blanchard and Diamond (1989), Pissarides (1985)]. Thus, a firm with a backward technology cannot credibly engage in job creation. Moreover, a firm with a state-of-the-art technology cannot credibly create jobs more than the amount required to meet its expected demand. Alternatively, one can assume that there is a fixed cost of maintaining a job position (sufficiently small to render expected discounted rewards from innovating positive). The existence of fixed costs induces the quality leaders minimize the amount of job positions and to create positions just sufficient to meet their expected demand.

[15] The fixed duration of search for a job position can be justified empirically, because the duration of unemployment roughly remained constant between 1969-89, the period covered by the Juhn et al. (1989) data [see National Economic Trends (1998)].

[16] The search process has the empirically relevant feature that if manufacturing is less-skilled labor intensive in absolute terms, that is, $A_L > A_H$, then the search period to find one unit of skilled labor y/A_H is longer than that of unskilled labor y/A_L.

[17] I assume that a worker is perfectly mobile between industries and activities at the instant she joins the labor force. There-after, the worker can be employed only in the activity in which she finds her first job. A newly-born worker who cannot find a job in R&D joins the unemployment pool and seeks manufacturing jobs for the rest of her life. On the other hand, a newly-born worker who finds an R&D job is guaranteed lifetime employment in R&D.

[18] Note that labor market equilibrium requires $sN(t) = u_H L_{HS}(t) + B_H(w_L, w_H)xIN(t) + A_H(w_L, w_H)M(t)$ and $(1 - s)N(t) = u_L L_{LS}(t) + B_L(w_L, w_H)xIN(t) + A_L(w_L, w_H)M(t)$ for skilled and less-skilled labor, respectively. Substituting $L_{HS}(t)$ and $L_{LS}(t)$ from equations (14) and (15) into the above equations immediately yields equations (16) and (17).

[19] Note that equations (16) and (17) can be restated as $A_iM(t) = (1 - u_i)L_{iS}(t)$ for i = H, L. Examining equations (14) and (15) implies that $L_{iS}(t)$ grows at a rate of n; thus one can show that $A_iM(t + y) = (1 - u_i)L_{iS}(t)e^{ny}$ for i = H, L. Substituting this equality into equation (18) and imposing the condition that v is fixed at the steady-state equilibrium yields equation (19).

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[20] The layoffs at time t take place due to innovations at time (t - y). Since the innovation rate is constant at the steady-state, the time index is omitted.

[21] Note that equations (16) and (17) can be rewritten as $A_iM(t) = (1 - u_i)L_{iS}(t)$ for i = H, L. Substituting this equality into equation (20) and imposing the condition that u_{iS} is constant at the steady-state equilibrium gives equation (21).

[22] See section 2.2.10 for the derivation of $u_S^* = u_{SL}^* = u_{SH}^*$.

[23] To see this, note that the LMC equation can be restated as $(1 - s)/s = B_L/B_H\ \psi + A_L/A_H(1 - \psi)$, where $\psi = B_HxI/s$. Hence, the LMC equation exhibits the standard properties of the Heckscher-Ohlin model [see Bhagwati and Srinisavan (1983), p. 62]. Complete specialization in R&D implies that $\psi = 1$, in which case $s/(1 - s) = B_L/B_H$ implicitly defines $(w_L^0)_{LM}$. On the other hand, complete specialization in manufacturing dictates that $\psi = 0$; thus, $s/(1 - s) = A_L/A_H$ implicitly determines $(w_L^1)_{LM}$.

[24] Note that the sufficient condition stated in Assumption 3 that $p(v^*) < \beta$ guarantees that even if $I^* = 0$ the economy experiences a minimum level of $u_S^* > 0$ due to biological unemployment.

[25] The model predicts that the unemployment rates of searching workers for both types of labor are equal to each other. However, this does not necessarily imply that the unemployment rates taken with respect to their corresponding labor endowments will be identical. More specifically, the unemployment rates are equal to $u_H = u_S^*(s - B_HxI)/s$ and $u_L = u_S^*(1 - s - B_LxI)/(1 - s)$ for skilled and less-skilled labor.

[26] I should emphasize that although u_S^* is the same for both types of labor, the equilibrium number of unemployed less-skilled workers remains higher than that of unemployed skilled workers if and only if manufacturing activity is less-skilled labor intensive, i.e., $A_L > A_H$.

[27] To see this note that with w_L falling and I rising, B_LxI increases. Since $u_R = (1 - s - B_LxI)/(s - B_HxI)$ has gone up, then B_HxI has to increase as well.

[28] The conditions can alternatively be stated as $A_H(B_{HL} + B_{LL}) - A_L(B_{HH} + B_{HL}) < 0$, $A_H(A_{HL} + A_{LL}) - A_L(A_{HH} + A_{HL}) < 0$. These conditions hold for Cobb-Douglas technology if and only if $w_H > w_L$. They also hold for CES production functions if w_H is sufficiently greater than w_L (i.e., $w_H >> w_L$).

[29] To see this, rewrite the steady-state equations (19) and (21) in the following form $\dot{v} = (I^* + \beta)(1 - u_S^*)e^{ny^*} - [p(v^*) + nv^*] = 0$, and $\dot{u}_S = (I^* + \beta)(1 - u_S^*) - p(v^*) = 0$. In each equation, the first term represents the rate of increase, whereas the second term represents the rate of decrease. These two equations imply that $(I + \beta)(1 - u_S)/(I + \beta)(1 - u_S) = [p(v^*) + n(v^*)]/p(v^*)e^{ny^*}$. Note that the LHS of the equality is equal to one and is invariant to any change in I. Therefore the vacancy rate does not change.

CHAPTER 3
SCHUMPETERIAN UNEMPLOYMENT, TRADE, AND WAGES

3.1. Introduction

There is a growing literature in economics that explores the causes of rising wage inequality in the United States over the last few decades.[1] Almost a unanimous agreement emerges that the wage inequality between skilled and less-skilled labor has increased because of the decline in the relative demand for less-skilled labor. In most of the recent studies, technological change has been advocated as an explanation for the deterioration in the earnings of less-skilled workers relative to the earnings of skilled workers. The globalization of the world economy, in particular, the increased North-South trade has also been proposed as an explanation for the rising wage inequality.[2] The trade effect has been rationalized by the Stolper-Samuelson Theorem, which requires a decline in the price of less-skilled-labor intensive importables in order to generate a fall in the wages of less-skilled workers.[3] Nevertheless, recent studies cast doubt on the empirical significance of any reduction in the prices of importables.[4] An alternative approach to linking trade liberalization to wage inequality, recently proposed by Dinopoulos and Segerstrom (1999), considers a Schumpeterian version of the Stolper-Samuelson mechanism. They argue that increased North-North trade can account for the rise in wage inequality without necessarily operating through changes in the relative prices of importables. In their setting, trade liberalization increases the rewards to innovation and results in lower wages for the less-skilled workers if and only if innovative activity is skilled-labor intensive relative to manufacturing of final products.

In this theoretical debate, researchers have rarely investigated the issue of wage inequality by introducing unemployment in an international trade context–despite the fact that the relative unemployment rate of less-skilled workers is a crucial determinant of their expected relative earnings. Most economists consider unemployment as a macroeconomic phenomenon that is by no means related to a microeconomic issue like international trade. It is argued that trade policies exert first-order effects on the optimal allocation of resources but has no significant impact on the rate of unemployment.[5] Notwithstanding the mainstream approach, a small body of literature has emerged, analyzing the interaction between trade and unemployment. However, this literature mostly confines itself to static models ignoring the growth structure of the economy, and therefore lack the dynamic linkages between trade and labor markets.[6] Bhagwati and Dehejia (1994) draw attention to the interconnection between trade and unemployment emphasizing the possible implications in a dynamic setting. They argue that increased globalization during the 1980's has contributed to the randomization of comparative advantage in different manufactured goods. The volatility in comparative advantage, in turn, has generated more labor turnover in the manufacturing sector, which intensively uses less-skilled labor. Hence, the natural rate of unemployment among the less-skilled workforce has risen, an effect that has also contributed to the decline in their expected relative earnings.[7,8] Building a model that incorporates this notion of shifting comparative advantage and its labor market implications constitutes one motivation of the present chapter. The other motivation is to formalize the link between trade, unemployment, and wage inequality that was empirically investigated by Murphy and Welch (1992) using U.S. data. [9]

In this chapter, I develop an analytical framework to explore the impacts of international trade on wages and unemployment. I argue that North-North trade liberalization can account for the stylized facts of the 1980's: the higher magnitudes of innovation, wage inequality, and less-skilled labor unemployment.[10] The chapter constructs a dynamic model of growth and knowledge-based trade of higher quality products between two structurally identical countries. The setting incorporates endogenous determination of innovation and skill formation, and a time-consuming process of job-matching to generate unemployment. In this model, trade originates from know-how differences between the two countries; thus, the frequency of global innovations acts a measure of randomization in comparative advantage. If, for instance, a domestic R&D firm successfully innovates in an industry with a foreign leader, the domestic firm replaces the foreign firm, reversing the initial pattern of trade. In equilibrium, the alternating trade pattern stimulates turnover among manufacturing workers, the magnitude of which determines the rate of frictional unemployment. The model establishes the linkage between globalization and volatility in comparative advantage by building a mechanism in which trade liberalization affects the profitability of R&D and thereby the global innovation rate.

In the model, the two-country world economy consists of a continuum of structurally identical industries. Firms in each country engage in two types of activities: manufacturing activity to produce final goods and innovative activity (R&D) to improve the quality of these goods. The technique of producing higher quality products is discovered through R&D races. There is free entry into each R&D race, and each firm chooses the intensity of R&D to maximize the expected returns from innovation. The winner of an R&D race (the quality leader) holds a patent to exclusively produce the state-of-the-art quality product. Price competition prevails in product markets, and consumers exhibit stronger preferences towards better quality products. Hence, the patent enables the quality leader to drive its technologically-backward rivals out of the global market. Therefore, only the leader firms are engaged in manufacturing and exporting of final goods. Governments in each country impose an ad-valorem tariff on imported goods thereby reducing the profit margin of the leader firms from sales abroad.

Adjustments in the tariff rates do not affect the relative market prices of importables, since product prices are solely determined by quality differences.

Finitely-lived individuals differentiated in terms of ability constitute the population of each country. The size of the population grows at a constant rate. The skill acquisition decision of each individual is endogenously determined. An individual who chooses to remain less-skilled can only find a job in manufacturing. She earns the less-skilled wage regardless of her ability and faces the possibility of being laid off at each instant in time. Moreover, she must experience a period of searching before being matched with a job. On the other hand, an individual who decides to become skilled must undergo training for a certain period without earning any income. Thereafter, she is guaranteed lifetime employment in R&D earning a wage that is positively related to her ability.

The steady-state of the economy is characterized by sequential R&D races, where firms compete to discover higher quality products. R&D firms can instantly find the skilled workers to be employed in innovative activity. The winner of an R&D race gains access to the leading technology, but must go through a search process to find the less-skilled workers to be employed in manufacturing. The successful firm instantly opens up vacancies in order to attract labor. While it is engaged in the search process, the incumbent firm supplies the market. Once all the initial job openings of the winner firm are matched with workers, the winner firm drives the existing producer out of the market by choosing a limit price equal to the incremental difference in the quality of the innovated product. The incumbent firm lays off its manufacturing workers forcing them to join the economy-wide unemployment pool. Thus, at the balanced-growth path, one observes successful innovators trying to fill their vacant positions and unemployed workers trying to match with the prospective employers. The creative destruction mechanism of firms (resulting from technological advancements) coupled with the time-consuming job-matching process generates frictional unemployment, which I call

Schumpeterian unemployment. The model identifies another source of unemployment that stems from the continuous inflows into the unemployment pool due to birth of workers. I appropriately call this component of frictional unemployment *biological unemployment.*

The findings of this chapter imply that a global reduction in tariffs results in higher rates of innovation and growth. The reduction in tariffs increases the profitability of innovative activity by raising the profit margin of the winner firm from sales abroad. Consequently, more firms enter the R&D races, and the demand for skilled labor–the only factor of R&D production–increases. The higher demand leads to a rise in the expected relative earnings of skilled workers. This induces a larger share of population to undergo training and become skilled. Consequently, the share of R&D workers in the aggregate workforce and the intensity of R&D activity both increase. On the other hand, the higher intensity of innovations causes an increase in the manufacturing unemployment rate by speeding up the creative destruction process among manufacturing firms. Due to the assumption of structural symmetry across industries and countries, the above changes occur in each industry and are global in nature.

In summary, trade liberalization works its effects through augmenting the rewards to innovation. It diminishes the expected relative earnings of less-skilled workers without creating a distortion in the price of importables. Trade liberalization also accelerates the pace of technological progress and increases the unemployment rate of the less-skilled labor force. In the context of the present model, one can establish some of these results through alternative channels such as exogenous improvements in the size of innovations or exogenous labor-saving technological change in manufacturing. However, the former channel distorts the relative price of importables, and neither of the explanations can account for the globalization effect. Consequently, trade liberalization remains as the only explanation consistent with the stylized facts. The other arguments, along with trade liberalization, may simply work to enhance the magnitude of the observed changes.

The rest of the chapter is organized as follows. Section 3.2 describes the building blocks of the model. Section 3.3 establishes the steady-state equilibrium and explores the effects of trade liberalization on the global economy. The last section concludes the chapter.

3.2. The Model

The model combines a variant of the two-country dynamic general equilibrium model of Dinopoulos and Segerstrom, (henceforth DS) (1999) with the job-matching structure of Aghion and Howitt, (henceforth AH) (1994) and the firm replacement mechanism developed in the second chapter. The framework of DS is a standard quality-ladders growth model that also incorporates endogenous skill formation and two different mechanisms to eliminate the scale effects on growth. However, DS do not incorporate unemployment into their setting. The present model simplifies the production structure of DS by assuming that only skilled workers are employed in R&D activity, and only less-skilled workers are employed in final good manufacturing. Moreover, instead of Cournot quantity competition in product markets assumed in DS, the present model investigates the implications of Bertrand price competition. The matching structure, similar to the one developed in AH, characterizes the search process between firms and workers. As an additional feature, the job-matching scheme of the present model considers the implications of population growth with finitely-lived individuals. The mechanism by which successful innovators replace incumbent firms in the presence of time-consuming job-matching is borrowed from the closed economy model outlined in chapter two.

3.2.1. Household Behavior and Skill Formation

The economy consists of a continuum of families, each of which is indexed by ability $\theta \in (0, 1)$. Members within the family are identical in terms of ability. The size of each family grows at a rate of $n = (\beta - \delta)$, where β and δ refer to birth and death rates, respectively. At time t the size of population equals $N(t) = N_0e^{nt}$, where N_0 denotes the initial level of population. Each member of a family is modeled as a finitely-lived agent for a fixed time period $D > 0$. Since the number of births at time t must be equal to the number of deaths at time $(t + D)$, I can express β and δ in terms of n and D as $\beta = (ne^{nD}/e^{nD} - 1)$ and $\delta = n / (e^{nD} - 1)$.

Households choose the allocation of consumption across goods at each instant in time and the pattern of consumption expenditure over time. I assume that transfers between family members are feasible so that each member of the family can realize the same level of consumption regardless of individual earnings.[11] A family with ability θ maximizes the discounted lifetime utility

$$F_\theta = \int_0^\infty N_0\, e^{-(\rho - n)t} \log Z_\theta(t)\, dt\,, \qquad (1)$$

where ρ is the subjective discount rate, and $\log Z_\theta(t)$ is the instantaneous utility of each household member

$$\log Z_\theta(t) \equiv \int_0^1 \log \Big[\, \sum_j \lambda^j\, d_\theta(j, \omega, t)\, \Big]\, d\omega\,, \qquad (2)$$

where $d_\theta(j, \omega, t)$ shows the quantity demanded of product quality j at industry ω at time t, and $\lambda > 1$ represents the size of quality improvements (innovation size). Each family allocates its per capita consumption $c_\theta(t)$ to maximize the instantaneous utility $Z_\theta(t)$ given prices at time t. The static maximization problem yields the unitary elastic demand function $d_\theta(t) = c_\theta(t)/p_M$, where $d_\theta(t)$ is the quantity demanded, $c_\theta(t)$ is the consumption expenditure per capita, and p_M is the relevant market price for the product in each industry that carries the lowest quality-adjusted price. The quantity demanded for all other products becomes zero. Whenever a tie occurs in the lowest quality-adjusted prices, I assume that consumers prefer the higher quality product. Given the static demand behavior, the intertemporal maximization problem of a family with ability θ reduces to

$$\max. \int_0^\infty N_0\, e^{-(\rho - n)t} \log c_\theta(t)\, dt \qquad (3)$$

subject to the budget constraint $\dot{A}_\theta(t) = W_\theta(t) + r(t)A_\theta(t) - c_\theta(t)N(t)$, where $A_\theta(t)$ denotes the financial assets of the family, W_θ is the expected wage income of the family, and r(t) is the instantaneous rate of return. The solution to this problem yields the usual differential equation

$$\frac{\dot{c}_\theta(t)}{c_\theta(t)} = r(t) - \rho , \qquad (4)$$

which implies that a constant per capita expenditure path is optimal when the market interest rate equals the subjective discount rate. At the steady-state equilibrium, consumption per capita remains constant; thus, $r(t) = \rho$. In the rest of the chapter, I focus on the balanced-growth path behavior and drop the time index for the variables that remain constant.

Each household must also decide whether to enter the labor force as skilled or less-skilled. Since the family members are identical, the decision of the family can be represented by the decision of an individual member. The level of ability is common knowledge to both workers and firms. Denote with u the unemployment rate of less-skilled workers, with w_L the wage of less-skilled workers and with w_H the wage per efficiency unit of labor for skilled workers. All three variables are constant at the steady-state equilibrium. A worker who chooses to remain less-skilled can only find a job in manufacturing. The less-skilled worker must go through a period of searching in order to find employment. Once matched with a job, she faces the possibility of being laid off at each instant of time. The less-skilled worker earns w_L regardless of her ability with an instantaneous probability of (1 - u)dt, where dt is a small interval of time. On the other hand, a worker who chooses to become skilled must undertake training for a period of time $T < D$. During training, the worker does not receive any income. Therefore, the cost of training is basically the foregone less-skilled wage earnings for a period of T. Once the training is over, the worker can provide services for performing R&D. Skilled labor is entitled to lifetime job security due to the assumption of instant job-matching in R&D

activity.[12] A skilled worker with ability θ earns θw_H for her remaining lifetime, i.e. for a period of (D - T).

The training decision of each family aims at maximizing the expected discounted family earnings given the level of ability. A family member with ability θ born at time t chooses training and becomes a skilled worker if and only if

$$\int_t^{t+D} e^{-\rho(s-t)} w_L(1-u)ds < \int_{t+T}^{t+D} e^{-\rho(s-t)} \theta w_H ds\,, \tag{5}$$

where the LHS of the inequality shows the expected lifetime earnings of a less-skilled worker, and the RHS denotes the earnings of a skilled worker.[13] Both expressions are appropriately discounted to time t at the steady-state interest rate $r(t) = \rho$. Rewriting equation (5) as an equality and solving for θ yield the critical ability level θ_0, which determines the skill distribution of population. All families with ability levels below θ_0 remain less-skilled, whereas those with ability levels above θ_0 undergo training and enter the workforce as skilled labor. This critical level of ability is given by

$$\theta_0 = \left[\frac{1-e^{-\rho D}}{e^{-\rho T}-e^{-\rho D}}\right]\frac{(1-u)w_L}{w_H} = \sigma\frac{(1-u)w_L}{w_H}\ , \tag{6}$$

where σ can be viewed as a measure of relative discount factor of less-skilled labor earnings with respect to skilled labor earnings. With $\sigma > 1$ and $\theta_0 < 1$ (which must hold in equilibrium), it follows that $w_H > (1 - u)w_L$. In other words, the instantaneous *expected* earnings per efficiency unit of skilled labor w_H is higher than that of a less-skilled worker $w_L(1 - u)$. An increase in σ induces more people to remain less-skilled by increasing the expected wage earnings of less-skilled labor. The economy-wide supply of less-skilled labor is

$$L(t) = \theta_0 N(t)\,, \tag{7}$$

where θ_0 now represents the fraction of population that remains less-skilled. In the skilled labor market a certain portion of the workers are under training, and the rest of the workers who have acquired the necessary skills are available for performing R&D services. The subpopulation with complete training consists of workers who are born between time (t - D) and (t - T) is given by

$$\int_{t-D}^{t-T} \beta(1 - \theta_0)\, N(s)\, ds = (1 - \theta_0)\phi N(t)\,, \tag{8}$$

where $\phi = [e^{n(D-T)} - 1]/[e^{nD} - 1] < 1$ is a measure that stands for the fraction of skilled workers with acquired skills. Since the average skill level of workers with complete training equals $(1 + \theta_0)/2$, multiplying this expression by $(1 - \theta_0)\phi N(t)$ gives the supply of skilled labor in terms of efficiency units

$$H(t) = \frac{(1-\theta_0{}^2)}{2}\phi N(t). \tag{9}$$

Equations (6), (7) and (9) fully characterize the supply side of the labor market. An increase in the *expected relative* returns to skilled workers $w_H/(1 - u)w_L$ leads to a fall in the supply of less-skilled workers, which is in turn reflected as a rise in the efficiency units of skilled labor. The steady-state growth rates of factor endowments are equal to n given the constant level of θ_0:

$$\frac{\dot{H}(t)}{H(t)} = \frac{\dot{L}(t)}{L(t)} = \frac{\dot{N}(t)}{N(t)} = n\,.$$

3.2.2. Product Markets and Trade

The world economy is comprised of two structurally identical countries, the Home country and the Foreign country. I will analyze the economy of the Home country, noting that the same analysis also applies to the Foreign country. The global market consists of a continuum of industries indexed by $\omega \in (0, 1)$. Firms participate in R&D races to discover higher quality products. The size of quality improvements for each product is given by λ. The winner of an R&D race holds a patent to exclusively produce the state-of-the-art quality product of a particular industry. This patent expires when further innovation occurs in that industry, and technology of production becomes common knowledge globally. The winner firm competes with a fringe of followers who can produce the inferior quality product. Production of one unit of final good requires one unit of less-skilled labor, regardless of the good's quality. Using the less-skilled wage rate w_L as the numeraire, it follows that the marginal cost of production is equal to one. Following the standard practice of quality-ladder growth models, I assume that firms compete in prices.

To analyze the static Nash equilibrium, consider first the case of a Home leader competing with Home followers in the Home market, and with Foreign followers in the Foreign market. In the Home market given the followers price at marginal cost, the Home leader charges the limit price $p_M = \lambda$. That is, the leader's quality adjusted price equals the marginal cost of each follower. Thus, the leader firm drives the followers out of the market. The Home leader's profit flow accruing from Home market sales is $\pi(t) = cN(t)(\lambda - 1)/\lambda$, where c denotes the consumption expenditure per capita in the Home country.

In the Foreign country, the Foreign government imposes an ad-valorem tariff τ on all imported goods. Given the Foreign followers charge marginal cost, the price that Foreign consumers face for the higher quality product cannot exceed λ. Let superscript F refer to Foreign variables. International arbitrage requires that the Home leader's post-tariff price p_M^F must satisfy $p_M^F(1 + \tau) = \lambda$, in which case no Foreign follower operates in the market. The Home leader receives $p_M^F = \lambda/ (1 + \tau)$ per unit of good sold in the Foreign market enjoying a profit margin of $[\lambda/(1 + \tau) - 1]$. I assume that the tariff rate is not prohibitive and lies in the range $0 \leq \tau < \lambda - 1$. This assumption ensures that the Home leader earns positive profits by exporting. With Foreign consumers facing a price of λ, the Foreign demand for the Home leader's product is equal to $cN(t)/\lambda$. Consequently the profits of the Home leader resulting from Foreign market sales are $\pi^F(t) = [\lambda/(1 + \tau) - 1]cN(t)/\lambda$. The total profit flow of the Home leader from global sales is $\pi^G(t) = cN(t)K(\tau)/\lambda$, where $K(\tau) = (\lambda - 1) + [(\lambda - 1 - \tau)/(1 + \tau)]$.

Notice that the existence of tariffs does not alter the product demand of Foreign consumers and the derived labor demand of Home leader to manufacture exportables. Tariffs in the specified range act as "rent extracting" devices that neither shift jobs away from the Home leader nor enable technologically-backward Foreign followers to compete successfully. Tariffs simply reduce the profits of the quality leaders by transferring rents from leader firms to governments. A reduction in the tariff rate increases the profit flow of a quality leader and renders investment targeted at R&D more profitable.

The pattern of trade is determined by know-how differences between the two countries, and therefore can be called knowledge-based trade. Only the leader firms in each country are engaged in manufacturing and exporting activities. These firms have access to the technique of producing the state-of-the-art quality product and can drive their technologically-backward rivals out of the global market. Due to the assumption of structurally identical countries and industries, one-half of the industries consists of Home leaders and one-half of the industries consists of Foreign leaders.

The less-skilled labor market equilibrium condition in the Home country is given by

$$(1 - u)\theta_0 N(t) = \frac{1}{2}\frac{2cN(t)}{\lambda}, \tag{10}$$

where u stands for the manufacturing unemployment rate (also for the unemployment rate of less-skilled workers). The LHS of equation (10) shows the supply of effective less-skilled labor [see equation (7)]. The RHS denotes the demand for less-skilled labor, the measure of Home leaders in the continuum (1/2) multiplied by the quantity demanded for each state-of-the-art quality product in the global market $2cN(t)/\lambda$. Equation (10) can be simplified to

$$c = \lambda(1 - u)\theta_0, \tag{11}$$

which relates consumption per capita to the manufacturing unemployment rate and to the critical level of ability.

3.2.3. R&D Races

In each industry firms engage in innovative activity to discover the next higher quality product. The arrival of higher quality products follows a Poisson process whose intensity equals $I(\omega,t) + I^F(\omega,t)$, which is the intensity of R&D at the global level. I assume that there is free-entry into each R&D race, and all firms have access to the same technology of R&D production. At each instant in time *a typical R&D firm j* of the Home country chooses the level of R&D intensity according to the production function $I_j(\omega,t) = H_j(\omega,t)/X(\omega,t)a$, where $I_j(\omega,t)$ denotes the probability of discovering the next higher quality product, $H_j(\omega,t)$ shows the level of skilled labor, $X(\omega,t)$ indicates a measure of R&D difficulty, and a stands for the unit labor requirement of innovative activity.

To remove the scale effects from the model, I employ two different specifications for $X(\omega,t)$. The first one is the PEG specification

$$X(\omega,t) = kN(t), \qquad k > 0, \qquad (12)$$

which captures the notion that the difficulty of performing R&D services is proportional to the size of the market. As the number of consumers grow in the market, it becomes more difficult to introduce new products and replace old ones. With this specification, tariffs have "permanent effects on growth." The second one is the TEG specification

$$\frac{\dot{X}}{X} = \mu(I(\omega,t) + I^F(\omega,t)), \qquad \mu > 0, \qquad (13)$$

which adopts the view that innovations that are relatively easy to discover tend to be discovered earlier. As the economy grows over time, it becomes more difficult to innovate superior products. It is called the TEG specification because tariffs have "temporary effects on growth" in this context.[14]

Let $I(\omega,t) = \Sigma_j I_j(\omega,t)$ and $H = \Sigma_j H_j(\omega,t)$ denote the Home country industry levels of innovative activity and skilled labor, respectively. Using the industry values, one can obtain

$I(\omega,t) = H(\omega,t)/X(\omega,t)a$, which implies that the arrival rate of innovations by Home country firms in industry ω increases with skilled labor employment. The *typical* Home firm in an R&D race maximizes the expected discounted profits

$$\Pi(\omega,t)\, I_j(\omega,t)dt - w(\omega,t)\, H_j(\omega,t)dt\,, \tag{14}$$

where $\Pi(\omega,t)$ represents the expected discounted profits of a *successful* innovator. Firm j enjoys Π with the instantaneous probability $I_j(\omega,t)dt$ and incurs the cost $w(\omega,t)H_j(\omega,t)dt$. Note that due to the normalization of less-skilled wage rate, $w(\omega,t)$ now stands for the *relative* wage of skilled workers per efficiency unit. Free-entry into R&D races implies that equation (14) must be equal to zero. The ω terms drop out in a symmetric equilibrium in which the intensity of R&D is the same across industries. In addition, the values at industry level represent the values at the aggregate level due to the assumption of continuum of industries. Using $I(t) = H(t)/X(t)a$, it follows that

$$\frac{\Pi(t)}{X(t)} = aw\,, \tag{15}$$

where the LHS is the relative price of innovation (adjusted by R&D difficulty), and the RHS is the marginal cost. Since there is constant returns to scale in innovative activity, the size of each R&D firm is indeterminate.

3.2.4. The Job-Matching Process

I analyze the job-matching mechanism between less-skilled workers and manufacturing firms, generalizing the search process of Aghion and Howitt (1994). The matching mechanism introduces a friction in the labor market so that workers and firms must search for each other before a successful job match is realized. Following Aghion and Howitt (1994), I assume that the less-skilled workforce as a whole is involved in the activity of seeking jobs regardless of being employed; thus, the notion of on-the-job search is explicitly incorporated. On the other hand, an R&D firm starts searching for workers only when it gains access to the leading technology.

Assume that there is a matching function $m(V(t),L(t))$ that determines the aggregate flow of completed job-matches as an increasing function of the aggregate level of vacancies $V(t)$ and the size of the less-skilled workers $L(t)$. The matching function is concave and homogenous of degree one in its arguments with positive marginal products. Dividing the flow of job matches by the size of the less-skilled workforce yields the aggregate job-finding rate $p(v(t)) = m(v(t),1)$, where $v(t) = V(t)/L(t)$ stands for the vacancy rate. Similarly, dividing the flow of job matches by the amount of vacancies gives the aggregate recruiting success rate, $q(v(t)) = m(1,1/v(t))$. At the balanced-growth path, vacancies and manufacturing workforce grow at the same rate; hence, $v(t)$ remains constant. The transition rates $p(v)$ and $q(v)$ must satisfy $q(v(t))V(t) = p(v(t))L(t) = m(V(t),L(t))$, which implies that the pool of successful job matches expands at the rate of population growth. Moreover, assume that $q(0) = p(\infty) = \infty$, $q(\infty) = p(0) = 0$, and $p(v) > 0$ for all v.

Let me now describe the mechanism by which manufacturing firms replace each other at the balanced-growth path when innovation takes place. When a winner firm gains access to the leading technology in an industry at time t, it instantly creates vacancies in order to attract labor. A successful job match for each position is realized after a search of duration y because of the time-consuming search process. While the winner is engaged in recruiting workers during the time interval $(t, t + y)$, the incumbent firm supplies the market. At time $(t + y)$ the emerging leader completes the initial job-matching process and replaces the incumbent firm.[15] The ex-quality leader lays off her workers forcing them to join the economy-wide unemployment pool. Further innovation in the industry triggers the same mechanism of creative destruction. In short, a successful innovator must forego a period of y as a non-producing leader involved in recruiting workers. Nevertheless, the same firm will have a chance to make up for that time when a new firm with superior technology emerges, because the new firm must go through the search process as well. Hence a fixed amount of time y is added and subtracted from the lifetime of the product, represented by the random variable η. Since the arrival of higher quality products follows a stochastic Poisson process, the interarrival time period of innovations η is distributed exponentially over an infinite horizon with the parameter $(I + I^F)$. The R&D intensities of both countries are equal to each other and remain constant at the steady-state. Thus, 2I represents the global rate of innovations. The vacancy creation scheme to be outlined in section 3.2.5 enables the producer to satisfy a constantly expanding demand and enjoy instantaneous profits growing at the rate of population growth. The expected discounted profits of a successful innovator is given by

$$\Pi(t) = e^{-\rho y} \{ \int_0^\infty 2Ie^{-2I\eta} [\int_0^\eta \pi^G(t)\, e^{-(\rho - n)s}\, ds]\, d\eta \}, \tag{16.a}$$

$$\Pi(t) = e^{-\rho y} \frac{\pi^G(t)}{(\rho + 2I - n)}, \tag{16.b}$$

where the bracketed expression in equation (16.a) stands for the discounted instantaneous profits of the leader firm realized for the duration of the product η. The expression in parenthesis is further discounted at the prevailing interest rate ρ for a period of y in order to account for the search time of the firm.

3.2.5. Steady-State Vacancy and Unemployment Flows

In this section, I derive the steady-state equations that govern the flow of vacancies at the aggregate level, and the flow of labor in and out of unemployment. I also consider the implications of population growth on the creative destruction mechanism. Denote with t the time of a new product discovery by a Home firm. At the steady-state equilibrium, a fraction Idt of industries have Home R&D firms as winners. Each successful Home firm realizes that during the search period–in which no output can be produced–the demand for its product will expand at the rate of population growth. Hence, the firm instantly creates vacant positions at time t at an amount equal to its expected labor demand at time (t + y), 2cN(t + y)/λ. At the same moment, in Idt of the industries each successful Home firm, and in ½(1 - 2Idt) of the industries (i.e., the measure of Home industries that have not experienced any innovation between time t and t + dt) each operating Home firm can perfectly foresee that they will be the only quality leaders that command manufacturing workers at time (t + y).[16] Hence, in a total of one-half of the industries, the quality leader Home firms must open up additional positions in order to accommodate the instantaneous growth in demand at time (t + y). More specifically, at time t the Home firms in ½ of the industries must create (β - δ)2cN(t + y)dt/λ positions to keep up with demand expansion and δ2cN(t + y)dt/λ positions to compensate for the loss of filled jobs due to death of employed workers. Thus, the steady-state flow of vacancies is given by

$$\dot{V}\,dt = I\frac{2cN(t+y)}{\lambda}dt + \frac{1}{2}\frac{\beta 2cN(t+y)}{\lambda}dt - m(V(t),L(t))dt\,, \tag{17}$$

where all variables except N, L and V are constant. The first expression in (17) refers to the inflow of vacancies due to innovations by Home firms, the second one represents the job openings by Home firms expecting to operate at time (t + y), and the third one stands for the flow of successful vacancy fillings given by the matching function. Notice that the vacancy creation scheme must follow a forward-looking approach to keep up with consumer demand. At the steady-state equilibrium the vacancy rate is fixed; thus, the growth rate of vacancies must be equal to the growth rate of population. Substituting for m(V(t),L(t)) = p(v)L(t) into (17) and using (7) and (11), I get the following balanced-growth relationship

$$\frac{\dot{V}}{V} = \frac{(2I+\beta)(1-u)e^{ny} - p(v)}{v} = (\beta - \delta)\,, \tag{18}$$

which equates the percentage increase in vacancies to the rate of population growth. In a similar fashion, I derive the steady-state unemployment flow of the economy

$$\dot{U}\,dt = \frac{1}{2}\frac{2cN(t)}{\lambda}2Idt + \beta L(t)dt - \delta uL(t)dt - m(V(t),L(t))dt\,, \tag{19}$$

where again all variables except N, L and V are constant. The first expression in equation (19) represents the Schumpeterian inflow into the unemployment pool, that is, the workers that are laid off due to technological advancements. In the continuum of industries with measure one, the Home country accounts for half of the leader firms each of which holds $2cN(t)/\lambda$ filled positions. The workers in these jobs are fired with the global probability of innovation 2Idt.[17] The second and third expressions capture the expansion and contraction in the unemployment pool due to the biological turnover of the labor force. Essentially, the second term stands for the flow of newly-born less-skilled workers who instantly join the unemployed labor force, and the third term designates the flow of death incidents among jobless workers. Finally, the fourth expression stands for the flow of successful job-matches. At the steady-state equilibrium the unemployment rate is constant; hence, the growth rate of unemployed workers must be equal to the growth rate of population. Substituting for $m(V(t),L(t)) = p(v)L(t)$ into (19) and using (7) and (11), I obtain the balanced-growth condition

$$\frac{\dot{U}}{U} = \frac{2I(1-u)+\beta-\delta u-p(v)}{u} = (\beta-\delta)\,, \tag{20}$$

which equates the percentage increase in unemployed workers to the rate of population growth. I can utilize (18) and (20) to find a unique solution for the steady-state equilibrium vacancy rate $v^* > 0$.[18] Note that v^* depends only on the rate of population growth and the specification of the matching technology.

To find the relation between the intensity of innovative activity and the rate of unemployment substitute $v = v^*$ into (20) and derive

$$I(u) = \frac{1}{2}\left(\frac{p(v^*)}{1-u} - \beta\right). \tag{21}$$

Lemma 1: *An increase in the intensity of innovative activity I leads to a rise in the manufacturing unemployment rate u, for $I > 0$.*

Proof. Totally differentiating (21) would immediately give the result.

In order to gain some insight on the lemma, rewrite (21) as

$$(2I + \beta)(1 - u) = p(v^*),$$

where the LHS denotes the rate of increase in the unemployment rate, and the RHS represents the rate of decrease in the unemployment rate. In essence, given the positive level of job-finding rate $p(v^*)$, the source of upward changes in unemployment rate can be decomposed into two parts. $2I(1 - u)$ accounts for the increase in the unemployment rate due to technological innovations, which generates *Schumpeterian unemployment*, whereas $\beta(1 - u)$ represents the increase in the jobless rate due to population expansion, which causes *biological unemployment*. Both mechanisms contribute to unemployment by increasing the rate of turnover among workers. An interesting implication of Lemma 1 is that an economy with an equilibrium unemployment rate u^* that satisfies $p(v^*)/(1 - u^*) < \beta$ experiences zero Schumpeterian growth, and innovative activity stops. This implies that an economy with no innovative activity suffers only from biological unemployment. Since the objective of this chapter is to analyze a setting in which both R&D and manufacturing activity take place, I assume that the equilibrium level u^* is such that $p(v^*)/(1 - u^*) > \beta$.[19] In addition, I assume that at the steady-state equilibrium, $p(v^*) > \beta$ which implies that biological turnover, by itself, is not sufficient to generate unemployment.[20]

3.3. Steady-State Equilibrium

To characterize the steady-state equilibrium, I will utilize the zero profit in R&D condition and the skilled-labor market equilibrium condition, together with a specification for R&D difficulty to remove the growth scale effects. Substituting w from equation (6) (with w_L

normalized to 1) and Π from equation (16.b) into the zero profit condition (15) using equations (11), (21), and $\pi^G(t) = cN(t)K(\tau)/\lambda$, I obtain the "free entry in R&D" equation

$$\frac{a\sigma x}{\theta_0} = \frac{e^{-\rho y}K(\tau)\theta_0}{\rho + 2I(u) - n}, \qquad \textbf{RD} \qquad (22)$$

which is indeed a restatement of the condition that the relative price of innovation (RHS) equals the marginal cost (LHS) in terms of the endogenous variables θ_0, u and x (per-capita R&D difficulty). Equating the supply of skilled labor (9) to the demand for skilled labor IX(t)a, and substituting for I from equation (21) yield the "labor market equilibrium" condition

$$p(v^*) = (1 - u)\left[(1 - \theta_0^2)\frac{\phi}{xa} + \beta\right], \qquad \textbf{LM} \qquad (23)$$

which simply states that the job-finding rate must be equal to the rate of increase in the unemployment rate generated by the Schumpeterian and biological turnover.

Proposition 1: *Under the assumptions of the model, a unique steady-state equilibrium exists in which the level of innovative activity I, the rate of manufacturing unemployment u, the fraction of workers that become less-skilled θ_0, and the level of consumption per capita c remain constant over time.*

Proof. See Appendix B.

The steady-state growth rate of the economy g is derived by calculating the growth rate in the instantaneous utility of representative individual. Substituting $d = c(t)/\lambda$ into (2), I obtain

$\log Z(t) = \log c(t) - \log\lambda + \int_1^0 \log\lambda^{j(\omega,t)}\,d\omega$, where $j(\omega,t)$ refers to the quality level of the highest quality product in industry ω at time t. The only term time dependent term in this expression is the integral term whose expected value equals $2It\log\lambda$. Hence, at the steady-state equilibrium, the Schumpeterian growth rate of the economy is given by

$$g = \frac{\dot{Z}(t)}{Z(t)} = 2I\log\lambda,$$

which defines the rate of growth as an increasing function of the intensity of global R&D activity and the size of innovations. The constant level of I in the presence of population growth guarantees that the growth rate of the economy is free of scale effects.

At the balanced-growth path of the two-country world economy, R&D firms in each country compete globally to discover the technique of producing higher quality products. The successful firm maintains temporary monopoly power in the global market after completing the initial hiring process. Introduction of superior products triggers the creative destruction mechanism by which new firms replace incumbent firms. Due to structural symmetry, in the Home country, one half of the goods are manufactured by the Home quality leaders and one half of the goods are exported from the Foreign ones. Each country's share of exportables remains fixed in equilibrium; however, the set of traded goods is constantly changing over time. If, for instance, a domestic R&D firm successfully innovates in an industry with a Foreign leader, the Home firm replaces the Foreign firm and reverses the initial pattern of trade. Hence, the frequency of innovations can be interpreted as a measure that determines the magnitude of randomization in comparative advantage. Any exogenous shock that results in a rise in the rate of innovations contributes to the increased randomization in trade pattern. The higher magnitude of volatility, in turn, puts upward pressure on the manufacturing unemployment rate (Lemma 1).

3.3.1. The PEG Model

To solve the model at the balanced-growth path, first consider the PEG specification defined by equation (12). Note that this specification fixes the level of per capita R&D difficulty x to the parameter k. The steady-state equilibrium of the PEG model is illustrated in Figure 3-1 by the intersection of RD and LM curves. The RD condition establishes a positive relationship between θ_0 and u. A higher unemployment rate is associated with a higher innovation rate through Lemma 1. The increased frequency of innovations increases the leader firm's

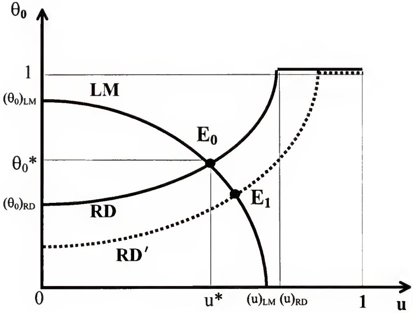

Figure 3-1: The Effects of Trade Liberalization in the PEG Model

probability of being replaced, thereby reducing the rewards to R&D production. To maintain equilibrium, the supply of less-skilled workers θ_0 must rise. This exerts its influence by two channels. First, the increased θ_0 expands the size of the manufacturing output and positively affects the expected discounted returns to innovation. Second, the increased θ_0 implies that more individuals have chosen to become less-skilled. This in turn dictates that a decline in the relative wages of skilled workers has occurred. The fall in relative wage of skilled labor implies a reduction in the marginal cost of R&D activity. Consequently, both channels diminish the price marginal cost differential in R&D and restore equilibrium.

The LM condition, on the other hand, establishes a negative relationship between θ_0 and u. A higher level of u decreases the rate of increase in the unemployment rate. As a result, the economy can sustain an increased level of labor turnover, which means a higher rate of innovation. Thus, production of R&D increases, and a larger fraction of the population chooses to become skilled, resulting in a lower level of θ_0.

At the steady-state equilibrium, one can also analyze the aggregate (economy-wide) unemployment rate, which is defined by the number of unemployed workers divided by the size of the population $u_A = U(t)/N(t)$. Using $U(t) = uL(t)$ and (7), it follows that $u_A = u\theta_0$, which states that the aggregate unemployment rate is determined by multiplying the manufacturing unemployment rate by the share of less-skilled labor in population. Note that the less-skilled labor unemployment rate is not a sufficient indicator to analyze variations in the economy-wide unemployment rate, because the skill distribution of the labor force is endogenously determined. For instance, a policy that increases the jobless rate of less-skilled workers diminishes their expected earnings. The change in wage income motivates more individuals to become skilled and escape unemployment, possibly mitigating (or overturning) the initial rise in the economy-wide unemployment rate.

Proposition 1: *In the PEG model a permanent reduction in trade barriers realized by a fall in the common tariff rate* τ *generates*

(i) *an increase in the expected relative wage earnings of skilled workers* $w/(1 - u)$,

(ii) *an increase in the proportion of workers that choose to become skilled* $(1 - \theta_0)$,

(iii) *an increase in the manufacturing unemployment rate* u,

(iv) *an increase in the aggregate unemployment rate* u_A *if and only if* u *remains below a critical level* u^c *implicitly defined by* $(2(1 - u^c) + \phi u^c)/(1 - u^c)^2 = 2(\beta + (\phi/ak))/p(v^*)$,

(v) *an increase in the level of innovative activity* I *and the growth rate* g.

Proof. See Appendix B.

Figure 3-1 displays the effects of trade liberalization in the PEG model. The RD curve shifts down resulting in a lower level of θ_0 and a higher level of u at the new equilibrium. Reduced trade barriers increase the profitability of R&D by augmenting the temporary monopoly profits enjoyed by a winner firm. This stimulates more firms to engage in R&D production, and the demand for skilled labor increases. The higher demand for R&D workers drives up their expected relative returns. The adjustment in earnings induces more individuals to undergo training and become skilled, thereby generating a supply response. As a result, the share of skilled workers in the labor force and the frequency of innovations both increase. On the other hand, the higher rate of innovations positively contributes to the randomization in comparative advantage. The increased volatility accelerates the turnover among manufacturing firms and leads to a rise in the manufacturing unemployment rate. Turning to the aggregate unemployment rate, two effects are observed. First, the increased manufacturing unemployment rate stimulates a rise in u_A through a direct effect. Second, the increased share of skilled labor generates a fall in u_A through an indirect effect (supply response). The reason is that a higher fraction of the population can escape unemployment by shifting to R&D positions, which are characterized by instant job-matching. The net effect of trade liberalization on u_A is positive if and only if u remains below the critical level u^c.

3.3.2. The TEG Model:

At the balanced-growth path of TEG model, R&D difficulty grows at a constant rate of n. Imposing this condition on equation (13) yields I = n/2μ, which defines the level of R&D activity in terms of the parameters n and μ. Substituting this into equation (21), I can explicitly determine the equilibrium rate of manufacturing unemployment as

$$u^* = 1 - \frac{p(v^*)}{(n/\mu) + \beta}, \tag{23}$$

which states that u* depends only on the specification of the job-finding rate, and on the exogenous parameters of the model n, μ and β. I assume that $p(v^*) - \beta < n/\mu$ in order to guarantee that u* lies in the interval (0, 1). Figure 3-2 illustrates the steady-state equilibrium of the TEG model by the intersection of RD and LM curves. The RD curve slopes upward in (θ_0, x) space. A higher level of per capita R&D difficulty x increases the marginal cost of R&D activity. To restore equilibrium an increase in the share of less-skilled labor θ_0 is required, an adjustment that operates through relaxing the manufacturing labor constraint and reducing the marginal cost of R&D. The LM curve slopes downward in (θ_0, x) span. An increase in x increases the cost of conducting R&D and stimulates a decline in the level of innovative activity. However, the long-run level of I is fixed by the exogenous parameters of the model. Hence, θ_0 must fall implying that more individuals choose to become skilled and enter the labor force as R&D workers. Consequently, the economy attains the initial intensity level of R&D.

Proposition 3: *In the TEG model a permanent reduction in trade barriers realized by a fall in the common tariff rate* τ *generates*

(i) *an increase in the expected relative wage earnings of skilled workers* $w/(1 - u)$,

(ii) *an increase in the proportion of workers that choose to become skilled* $(1 - \theta_0)$,

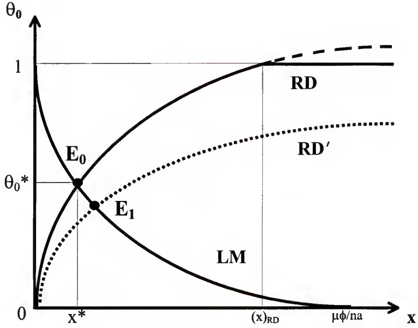

Figure 3-2: The Effects of trade liberalization in the TEG model

(iii) *no effect on the long-run manufacturing unemployment rate,*

(iv) *a decrease in the aggregate unemployment rate* u_A,

(v) *a temporary increase in the level of innovative activity I and the growth rate g, with no effects on their long-run levels.*

Proof. See Appendix B.

Figure 3-2 demonstrates the effects of trade liberalization in the TEG model. The RD curve shifts down resulting in a lower level of θ_0 and a higher level of x at the new equilibrium. A reduction in the common tariff rate increases the expected rewards of innovating. This encourages more firms to engage in R&D activity, and the demand for skilled labor increases. The higher demand stimulates an increase in the expected relative returns to skilled labor, motivating more individuals to undergo training. As the supply of skilled labor increases, the rate of innovative activity temporarily increases. However, the long-run level of R&D activity is fixed by the unchanged parameters of the model; thus, per capita R&D difficulty must rise to bring the R&D intensity back to its initial level. At the new equilibrium the rates of u and I are unchanged, but the permanent rise in the share of workers choosing to become skilled $(1 - \theta_0)$ implies that their expected relative returns $w/(1 - u)$ have increased. The variation in the aggregate unemployment rate is stimulated by the indirect effect only. More specifically, the higher expected skilled wage premium induces more individuals to become R&D workers and escape unemployment. Therefore, the economy-wide rate of unemployment permanently declines.

3.3.3. Steady-State Welfare Analysis

The expected discounted utility of a household over an infinite horizon F (given the level of ability and N_0 normalized to 1) is calculated by using equation (1) and the properties of the stochastic Poisson process.[21] At the steady-state F is given by

$$F = \frac{1}{(\rho - n)}\left[\log c - \log\lambda - \frac{2I(\log\lambda)}{(\rho - n)}\right], \tag{24}$$

where $c = \lambda(1 - u)\theta_0$ and $I = 1/2[(p(v^*)/(1 - u)) - \beta]$. Proposition 4 summarizes the implications of trade policy on steady-state welfare.

PROPOSITION 4. *The common tariff rate* τ^* *that maximizes the steady-state welfare is*

(i) $\tau^* > 0$ *positive for the PEG model under a sufficient condition* $2\log\lambda/(\rho - n) < (\phi/ak) + \beta$.

(ii) $\tau^* = (\lambda - 1)$ *for the TEG model.*

Proof. See Appendix B.

To explore the intuition, I focus on equation (24) and its components. In the PEG model, trade liberalization exerts its influence on welfare through consumption per capita and the intensity of innovations. Reduced trade barriers stimulate a rise in u and a fall in θ_0. Both adjustments adversely affect the level of per capita consumption and make the households worse off. On the other hand, as freer trade increases the global rate of innovations, consumers enjoy better quality products at an increasing rate. Thus, households become better off. The two opposing forces on welfare imply the existence of an optimal tariff rate under the sufficient condition stated in Proposition 4.

In the TEG model, trade liberalization affects the steady-state welfare only through consumption per capita. When tariffs are reduced, θ_0 decreases and u remains constant. Since more workers choose to become skilled, the fraction of population working in manufacturing declines.[22] The contraction in the size of the manufacturing output is reflected as a reduction in per capita consumption, which has a detrimental effect on welfare. Hence, the optimal tariff rate must approach to $\tau^* = \lambda - 1$, which is the upper bound specified in Section 3.2.2.

3.4. Conclusion

The model developed in this chapter provides an analytical framework to investigate the interaction between wage inequality and trade in the presence of unemployment. By building a dynamic general equilibrium model, I attempt to explore the insight of Bhagwati and Dehejia (1994) by which they argue that freer trade has accelerated the randomization in comparative advantage and increased the frictional unemployment rate of less-skilled workers by speeding up their turnover. In the present setting, know-how differences between two structurally identical countries determine the pattern of trade. The endogenous job-reallocation mechanism due to technological advancements coupled with the search process generates Schumpeterian unemployment. The structure of the model captures the conjecture of Bhagwati and Dehejia (1994) through a mechanism in which trade liberalization affects the rewards to innovation and thereby exerts a direct impact on the global innovation rate. The frequency of innovations, in turn, sets the magnitude of randomization in comparative advantage by which the unemployment rate of less-skilled labor is determined. The findings of the model imply that North-North trade liberalization is consistent with rising relative wage inequality and increasing unemployment among less-skilled workers. The analysis confirms the results of DS (1999) regarding trade liberalization and wage inequality in a setting with frictional Schumpeterian unemployment.

For future research several extensions can be suggested. A North-South model of trade with fundamentally different countries might yield interesting implications. Alternatively, a model with two identical countries that differ only in their job-matching technologies can incorporate some differences between Europe and the United States in terms of their employment flexibility and differential rates of labor turnover. Moreover, issues like minimum wage legislation or costly firing of workers can be addressed within the structure of the model.

3.5. Notes

[1] Deardoff and Hakura (1994), and Johnson (1997) provide overviews on the issue.

[2] See Wood (1995), and Borjas and Ramey (1994).

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[3] Bhagwati (1995) elaborate more on the limitations of the Stolper-Samuelson mechanism in explaining the observed changes.

[4] See Lawrence and Slaughter (1993), and Sachs and Shatz (1994) who investigated this issue. The first study found no change in the relative price of less skilled intensive commodities, whereas the second study found a small relative price decline.

[5] See Mussa (1993) and Krugman (1993) who have advocated the mainstream view.

[6] Brecher (1974) constructs a Heckscher-Ohlin-Samuelson model of trade in which unemployment arises due to minimum wage restrictions. Matusz (1996) addresses the same issue in a monopolistically competitive setting in which unemployment results from efficiency wages. Davidson et al. (1996) explore the relationship between trade and unemployment in a Ricardian model of trade where unemployment is generated by a time-consuming job-matching process. Utilizing the framework of Brecher (1974), recently Davis (1998), and Davis and Reeve (1997) analyze the global implications of trade and technology in a setting where one country imposes a binding minimum wage for the less-skilled.

[7] In particular, Bhagwati and Dehejia (1994) argue that the margin of comparative advantage becomes narrower as a result of more rapid diffusion of technology and increased integration of world markets. They call this rapidly shifting pattern of trade "kaleidoscopic comparative advantage". Dehejia (1996) constructs a simple model to analyze the relationship between increased labor turnover and returns to less-skilled labor using simulation methods

[8] Berman et al. (1994) report that during the 1980's trade as a share of U.S. manufacturing increased by about 30 percent. Gordon (1997) documents the rise in the natural rate of unemployment during this era of increased trade. In addition, for the same period, Davis et al. (1996) portray an increase in manufacturing sector job-reallocation rate, measured by the sum of job-creation and job-destruction rates.

[9] More specifically, by analyzing the U.S. data for 1963-1989, Murphy and Welch (1992) conclude that "higher unemployment lowers wages for younger and less educated workers relative to older and more educated workers". Regarding the trade effect, they state that "an increase in the durable goods deficit equal to 1 percent of GNP reduces the wages for young high school graduates by about 3 percent while raising the wages for older and more educated workers by 1 to 2 percent".

[10] Kortum (1997) reports a significant increase in the annual flow of patent applications in the U.S. during the 1980's compared to 1960's and 1970's, providing evidence for the increased rate of innovation.

[11] The feasibility of transfers between family members simplifies the dynamic optimization problem by avoiding truncation in individual income. One can also assert that the intrafamily transfers perfectly insure each member of the household in case of unemployment and training.

[12] Associating unemployment with one type of labor or with one type of activity, although not realistic, is commonly used in literature. See in particular Davidson et al. (1988) and Brecher (1974).

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[13] This condition is equivalent to maximization of the family's discounted utility. See DS (1999) for details.

[14] The TEG specification is formalized by Segerstrom (1998), and the PEG specification is proposed by Dinopoulos and Thompson (1996). Time series evidence based on U.S. annual data over the period 1950-90 provided by Dinopoulos and Thompson (1999b) suggests that one cannot reject one specification in favor of other.

[15] Note that when the patent expires at time t, any follower (Home or Foreign) can create open positions and successfully complete the recruiting of process by time $(t + y)$. However, at time $(t + y)$ it is certain that the new quality leader also replaces these followers by choosing a relative price proportional to the difference in quality. Hence, at the steady-state equilibrium no follower engages in vacancy creation and search activity.

[16] Note that any firm that discovers a higher quality product during the interval $(t, t + y)$ must experience a search of duration y.

[17] The layoffs at time t take place due to innovations at time $(t - y)$. Since the innovation rate is constant at the steady-state equilibrium, the time index is omitted.

[18] To see this note that rewriting equation (20) yields $(2I + \beta)(1 - u) = p(v)$. Substituting this expression into equation (18) gives $e^{ny} - 1 = n/q(v)$, which defines a unique value for v.

[19] A sufficient condition for the existence and uniqueness of the steady-state equilibrium for the PEG specification is $0 < a\sigma k e^{\rho y}(\rho - n)(\rho - n + p(v^*) - \beta)/ K(\tau) < 1 - [ak(p(v^*) - \beta)/\phi]$. The necessary and sufficient condition for the TEG specification is $0 < p(v^*) - \beta < n/\mu$. The derivation of these conditions are contained in Appendix B.

[20] Assuming $p(v^*) < \beta$, instead, results in an economy in which a minimum level of unemployment u_B must be observed due to the biological unemployment. The difference between the realized unemployment rate u^* and the biological unemployment rate u_B, then, accounts for the Schumpeterian unemployment rate.

[21] For the derivation of the steady-state welfare see Dinopoulos (1994).

[22] See Krugman (1995) for evidence on the decline of manufacturing output.

CHAPTER 4
MINIMUM WAGE EFFECTS ON UNEMPLOYMENT AND GROWTH IN THE GLOBAL ECONOMY

4.1. Introduction

Over the past twenty years, labor markets in the United States and Europe have experienced several changes. In the U.S., where the labor market is flexible, the change took the form of increasing wage inequality between skilled and less-skilled labor. In Europe, where the labor market is more rigid, the adjustment manifested itself as increasing rate of unemployment.[1]

A large number of empirical and theoretical papers have analyzed the underlying causes of these distinct labor markets developments. The most common explanation for the impoverishment of less-skilled workers is that the relative demand for less-skilled workers declined globally, and the supply response did not catch up with the demand shift. Given the institutional differences on the two sides of the Atlantic, this caused rising wage differential in the U.S. and higher unemployment in Europe.[2]

There are two strands of literature on wage income inequality. First, several individual country studies focus on supply and demand adjustments, and differences in institutional structure. Second, comparative labor market studies attempt to identify common explanatory variables, exploring the developments in a set of countries.[3] However, as Davis (1998) points out the implications of the proposed explanations may be quite different depending on whether the economies are separate entities or integrated through trade. Thus, even though the diverse experiences of Europe and U.S. seem to depend on local parameters, in a globally integrated economy, one must consider the repercussions of local shocks through the web of trade. In this vein, building on Brecher's (1974) seminal work, Davis (1998, 1999) analyzed the effects of minimum-wage legislation using a two-country Heckscher-Ohlin (henceforth H-O) model of trade, calling the country with flexible wages America and the country with rigid wages Europe.[4] To tackle with the issue of wage inequality, Davis and Trevor (1997) incorporated endogenous human capital formation by which observed wages can differ between the two countries.

In this chapter, I develop a dynamic general equilibrium knowledge-based model of trade between two countries with different labor market institutions. Following the terminology of Davis and Reeve (1997) and Krugman (1995), I call the economy with flexible wages America and the economy with the rigid less-skilled wage Europe. In the model, the decision of a worker to enter the labor force as skilled or less skilled is endogenously determined.[5] Entrepreneur firms of both countries participate in global R&D races to innovate higher quality products. Conducting R&D requires skilled labor. The winner of the R&D race sustains temporary monopoly power in the global market and sells its product in both American and European markets. Manufacturing of final products utilizes less-skilled labor. At a steady-state equilibrium with both countries producing non-negligible units of output, the manufacturing costs between the countries must be equalized. This requires the wage rates of the less-skilled labor be identical in both countries.

The model differs from the standard H-O model in many aspects. First, the relative prices of commodities are determined by quality differences, which are fixed by assumption. Therefore, global shocks do not operate through altering the commodity prices, as in the H-O framework.[6] Second, the growth and R&D dynamics of the world economy are explicitly incorporated into the model. Consequently, the pattern of trade is determined by knowledge differences in producing higher quality products (unlike the H-O model, where trade is driven by knowledge differences in relative factor endowments).[7] Third, the dynamic competition to capture leadership in a continuum of industries provides an additional integrating link between the countries, which is absent in the H-O models. In essence, the two regions participate in a zero-sum competition, where one country's leadership position comes at the expense of the other country. Therefore, any exogenous shock that alters the distribution of leadership in the world economy affects the wage and unemployment rates.

The objective of this chapter is to investigate the underlying causes of the distinct experiences of Europe and U.S., using a simple knowledge-based model of trade that incorporates endogenous R&D based growth and human capital formation. The main point of the present chapter is that a variety of global and local shocks can account for the stylized differences between Europe and U.S. labor markets. The model establishes several novel comparative steady-state results including adjustments in the minimum wage rate, technological change in R&D and manufacturing, changes in the distribution of the global population across countries, and variations in unemployment benefits. The model provides a new framework to stimulate both empirical and theoretical researchers to consider the labor market issues in a global economy where continuous competition to innovate generates random switches and determines the pattern of trade.

The rest of the chapter consists of three parts. Section 2 develops the main elements of the model. Section 3 presents the comparative steady-steady results and discusses the underlying intuition. The last section concludes the chapter. The proofs of all propositions are contained in Appendix C.

4.2. The Model

The building blocks of the model are borrowed from several studies. Household behavior, R&D races, and product market structure come from the standard quality-ladders model of growth without scale effects. The trade structure builds on the work of Grossman and Helpman (1991b). The introduction of endogenous human capital formation follows the study of Dinopoulos and Segerstrom (1999) which in turn builds on the papers by Findlay and Kierzkowski (1983), and Borsook (1987). The removal of scale effects from the endogenous growth model is along the lines of Dinopoulos and Thompson (1996, 1998).

4.2.1. Household Behavior and Skill Formation

The global economy consists of two countries, America and Europe. Superscripts A and E will refer to American and European variables, respectively. The parameters that do not bear either A or E are common to both countries. Each country is endowed with skilled and less-skilled labor. The countries differ in one important aspect. In America, flexible wages prevail in both skilled and less-skilled labor markets. In Europe, flexible wages prevail only in the skilled labor market. The minimum wage legislation in the less-skilled labor market generates unemployment.

Each economy consists of a continuum of families, indexed by their ability level $\theta \in (0, 1)$. All members within a family have identical ability. The size of each family grows at a rate of $n = \beta - \delta$, where the exogenous parameters β and δ refer to birth and death rates, respectively. Each member of a family lives for a finite period of time $D > 0$. The size of the global population at time t equals $N(t) = N_0 e^{nt}$, where N_0 denotes the initial level of the global population. Each country accounts for a fixed fraction of the global population given by η^i, for $i = A, E$.

Households choose the allocation of consumption across goods at each instant in time and the pattern of consumption over time. I assume that transfers between family members are feasible. The transfers guarantee that each family member has the same level of consumption regardless of individual earnings. A family with ability θ in country i maximizes the discounted lifetime utility

$$F_\theta^i = \int_0^\infty \eta^i N_0 \, e^{-(\rho - n)t} \log Z_\theta^i(t) \, dt, \qquad \text{for } i = A, E, \qquad (1)$$

where ρ is the subjective discount rate, and $\log Z_\theta^i(t)$ is the instantaneous utility of each household member

$$\log Z_\theta^i(t) \equiv \int_0^1 \log[\sum_j \lambda^j d_\theta^{\,i}(j,\omega,t)]\,d\omega, \qquad \text{for } i = A, E, \qquad (2)$$

where $d_\theta^i(j, \omega, t)$ shows the quantity demanded of product quality j at industry ω at time t, and $\lambda > 1$ represents the size of quality improvements (innovation size). Each family allocates the per capita consumption $c_\theta^i(t)$ to maximize the instantaneous utility $Z_\theta^i(t)$ given prices at time t. The static maximization problem yields the unitary elastic demand function $d_\theta^i(t) = c_\theta^i(t)/p$, where $d_\theta^i(t)$ is the quantity demanded, $c_\theta^i(t)$ is the consumption expenditure per capita, and p is the relevant market price for the product in each industry that carries the lowest quality-adjusted price. The quantity demanded for all other products becomes zero. Whenever a tie occurs in the lowest quality-adjusted prices, I assume that consumers prefer the higher quality product. Given the static demand behavior, the intertemporal maximization problem of a family with ability θ reduces to

$$\max. \int_0^\infty \eta^i N_0\, e^{-(\rho - n)t} \log c_\theta^i(t)\, dt, \qquad \text{for } i = A, E, \qquad (3)$$

subject to the budget constraint $\dot{A}_\theta^{\,i}(t) = W_\theta^i(t) + r^i(t)A_\theta^i(t) - c_\theta^i(t)\eta^{\,i}N(t)$, where $A_\theta^i(t)$ denotes the financial assets of the family, W_θ^i is the expected wage income of the family, and $r^i(t)$ is the instantaneous rate of return. The solution to this problem yields the usual differential equation

$$\frac{\dot{c}^i{}_\theta(t)}{c^i{}_\theta(t)} = r^i(t) - \rho\,, \qquad \text{for } i = A, E. \qquad (4)$$

This equation implies that a constant per capita expenditure path is optimal when the market interest rate equals the subjective discount rate. At the steady-state equilibrium consumption per capita remains constant; thus, $r^i(t) = \rho$. In the rest of the chapter, I focus on the balanced-growth path behavior and drop the time index for the variables that remain constant.

Each household must also decide whether to enter the labor force as skilled or less-skilled. The ability level of individuals is common knowledge to both workers and firms. Denote with u^i the unemployment rate of less-skilled workers, with $w_L{}^i$ the wage of less-skilled labor and with $w_H{}^i$ the wage per efficiency unit (i.e. wage per ability level) of skilled worker. All three variables are constant at the steady-state equilibrium. A worker who chooses to remain less skilled can only find a job in manufacturing.[8] The less-skilled worker earns $w_L{}^i$ regardless of her ability with a probability of $(1 - u^i)$. On the other hand, a worker who chooses to become skilled has to undertake training for a period of time $T < D$. During the training the worker does not receive any income. Therefore, the cost of training is basically the foregone less-skilled wage earnings for a period of T. Once the training is over, the worker can provide services for R&D activity. Skilled labor is entitled to lifetime job security due to the assumption of flexible wages in the skilled labor market. A skilled worker with ability θ earns a wage that increases with her ability level $\theta w_H{}^i$ for her remaining lifetime.

The training decision of each family aims at maximizing the expected discounted family earnings given the level of ability. Since the family members are identical in terms of their ability, I investigate the training decision of a representative family member. A family member with ability θ born at time t chooses training and becomes a skilled worker if and only if

$$\int_t^{t+D} e^{-\rho(s-t)} w_L{}^i (1 - u^i) ds < \int_{t+T}^{t+D} e^{-\rho(s-t)} \theta w_H{}^i ds, \qquad \text{for } i = A, E, \qquad (5)$$

where the LHS of the inequality shows the expected lifetime earnings of an less-skilled worker, and the RHS denotes the earnings of a skilled worker.[9] Both expressions are appropriately discounted to time t at the steady-state interest rate $r^i(t) = \rho$. Rewriting equation (5) as an equality and solving for θ yield the critical ability level $\theta_0{}^i$, which determines the skill distribution of population. All families with ability levels below $\theta_0{}^i$ remain less skilled, whereas those with ability levels above θ_0^i undergo training and enter the workforce as skilled labor.[10] This critical level of ability is given by

$$\theta_0^i = \left[\frac{1-e^{-\rho D}}{e^{-\rho T}-e^{-\rho D}}\right]\frac{(1-u^i)w_L^i}{w_H^i} = \sigma\frac{(1-u^i)w_L^i}{w_H^i}, \qquad \text{for } i = A, E, \qquad (6)$$

where σ represents a measure of relative discount factor of less-skilled labor earnings with respect to skilled labor earnings. With $\sigma > 1$ and $\theta_0^i < 1$ (which must hold in equilibrium), it follows that $w_H^i > (1 - u^i)w_L^i$. In other words, the instantaneous *expected* earnings per efficiency unit of skilled labor w_H is higher than that of a less-skilled worker $w_L^i(1 - u^i)$. Note that in America less-skilled wages are flexible hence $u^A = 0$, whereas in Europe the binding minimum wage $w_L{}^*$ implies that $u^E > 0$. Thus, the training arbitrage condition for Europe and America are:

$$\theta_0^A = \sigma\frac{w_L^A}{w_H^A}, \qquad \textbf{TA(A)} \qquad (7)$$

$$\theta_0^E = \sigma\frac{(1-u^E)w_L{}^*}{w_H^E}. \qquad \textbf{TA(E)} \qquad (8)$$

The economy-wide supply of less-skilled labor excluding the unemployed workers is

$$L^i(t) = \theta_0^i\eta^i N(t), \qquad \text{for } i = A, E, \qquad (9)$$

where θ_0^i now represents the fraction of the population that remains less skilled. In the skilled labor market a certain portion of the workers are under training, and the rest of the workers who have acquired the necessary skills are available for performing R&D services. The subpopulation with complete training consists of workers who are born between time (t - D) and (t - T) is given by

$$\int_{t-D}^{t-T} \beta(1 - \theta_0^i)N(s)\,ds = (1 - \theta_0^i)\phi N(t), \qquad \text{for } i = A, E, \qquad (10)$$

where $\phi = [e^{n(D-T)} - 1]/[e^{nD} - 1] < 1$ is a measure that stands for the fraction of skilled workers who have completed their training. The average skill level of those workers equals $(1 + \theta_0^i)/2$. Thus, multiplying the average skill level by $(1 - \theta_0^i)\phi\eta^i N(t)$ gives the supply of skilled labor in terms of efficiency units

$$H^i(t) = \frac{(1-(\theta_0^{\ i})^2)}{2}\phi^i\eta^i N(t), \qquad \text{for } i = A, E. \qquad (11)$$

Equations (6), (9) and (11) fully characterize the supply side of the labor market for each country. The steady-state growth rates of factor endowments are equal to n given the constant level of θ_0^i:

$$\frac{\dot{H}^i(t)}{H^i(t)} = \frac{\dot{L}^i(t)}{L^i(t)} = \frac{\dot{N}^i(t)}{N^i(t)} = n\,, \qquad \text{for } i = A, E.$$

4.2.2. Product Markets and Trade

The global market consists of a continuum of industries indexed by $\omega \in (0, 1)$. R&D firms of both countries discover higher quality goods by participating in industry-specific sequential and stochastic R&D races. Production of one unit of final good requires b units of less-skilled labor regardless of quality. The winner of an R&D race can produce a product that is λ times better than the existing product. Price competition prevails in the product markets. Therefore, the quality leader can drive its closest rival out of the market by charging a price that is λ times as high as the marginal cost of the rival. In this way, the leader captures the entire world market and sells its high quality product to both America and Europe. The nearest rival producing the previous generation product can do no better than break-even.

Let me distinguish leader firms by their country of origin and by the location of their nearest competitor. Denote with P^{ij} the price charged by a leader firm located in country i whose nearest rival resides in country j. To maximize profits the leader firm charges

$$P^{ij} = \lambda b w_L^j, \qquad \text{for } i = A, E, j = A, E.$$

Denote the per capita consumption of a world citizen with c. The leader firm sells $cN(t)/P^{ij}$ units to the global market. The profit margin for each unit sold is equal to $(\lambda bw_L^j - \lambda bw_L^i)$. Thus, the profit flow of the leader is

$$\pi^{ij} = \frac{cN(t)}{\lambda bw_L{}^j}(\lambda bw_L{}^j - bw_L{}^i), \qquad \text{for } i = A, E, j = A, E. \tag{12}$$

Note that R&D firms in each country may target their research at the state-of-the-art good currently produced either domestically or abroad. The profit flow equation suggests that firms earn higher profits when their nearest competitor resides in the country that exhibits higher unit cost of manufacturing. Thus, entrepreneurs, regardless of their location, will prefer to target the products currently manufactured in the high-cost country.

The above implication, however, is not consistent with a steady-state equilibrium, where both countries manufacture non-negligible amounts final goods. To see this, consider an equilibrium in which America, for instance, exhibits higher unit cost of manufacturing. Then entrepreneurs in both countries will target the industries of America. Each success by a European entrepreneur will permanently take the industry leadership away from America. Over time, America would lose its competitiveness in all industries. Such a situation contradicts with a steady-state equilibrium with both countries actively engaged in manufacturing. Hence, at the steady-state equilibrium the unit cost of manufacturing must be equalized between the countries. [11] Obviously, the immediate implication is that the manufacturing wage rate of less-skilled labor in America must be equal to the binding minimum wage in Europe. Lemma 1 states the implication of such a steady-state equilibrium on less-skilled wages.

Lemma 1: *If both countries engage in manufacturing at the steady-state equilibrium, then*

$$w_L{}^A = w_L{}^E = w_L{}^* . \tag{13}$$

Using Lemma 1, the profit flow of a leader firm can be simplified to

$$\pi^{ij} = \pi = \frac{(\lambda - 1)}{\lambda} cN(t). \tag{14}$$

4.2.3 R&D Races

Entrepreneurs in both countries must engage in innovative activity in order to participate in R&D races. I assume that there is free entry into R&D races, and all entrepreneurs within the same country have access to the same technology of R&D production. To remove the scale effects from the model, I introduce R&D difficulty $X(\omega,t)$ specified as

$$X(\omega,t) = kN(t), \qquad k > 0. \tag{15}$$

The specification suggests that the difficulty of conducting innovative activity is proportional to the size of the global market. It captures the notion that as the number of consumers grow in the market introducing new products and replacing old ones become more difficult.[12]

Free-entry into R&D races drives the expected profits of a *typical* entrepreneur firm down to zero. Let Π^i represent the expected discounted profits of a *successful* innovator located at country i, and $aX(t)$ stand for the unit labor requirement of innovative activity adjusted by the R&D difficulty. Thus, the zero profit condition implies that

$$\Pi^i(t) = aw_H^iX(t), \qquad \text{for } i = A, E, \tag{16}$$

where the LHS is the rewards to innovating and the RHS is the marginal cost of an R&D firm located at country i.[13]

The next step is to calculate the value of a successful firm Π^i at the steady-state equilibrium. There is a global stock-market that channels the consumer savings to firms engaged in R&D. Each R&D firm issues a stock that pays the flow of monopoly profits if the firm wins the race and zero return otherwise. Let I^{ij} denote the aggregate intensity of R&D by entrepreneurs in country i targeted at leaders in country j. Hence, a leader in country i faces an instantaneous probability $(I^{Ai} + I^{Ei})dt$ of being replaced by an entrepreneur firm (dt represents a small interval of time). Let $I^i = I^{Ai} + I^{Ei}$ denote the world-wide R&D intensity targeting industry i. The stockholder suffers a loss of Π^i with the probability of innovation $I^i dt$. The event of no innovation occurs with probability $(1 - I^i dt)$. In this case the stockholder realizes an appreciation of $d\Pi^i = \dot{\Pi}^i dt$. No arbitrage condition in the stock market requires the expected rate of return of a successful firm to be equal to the interest rate r^i:

$$\frac{\dot{\Pi}^i}{\Pi^i}(1 - I^i dt)dt - \frac{(\Pi^i - 0)}{\Pi^i} I^i dt + \frac{\pi^i}{\Pi^i} dt = r^i dt, \qquad \text{for } i = A, E.$$

Taking limits as dt → 0 yields

$$\Pi^i = \frac{\pi}{\left[r^i + I^i - \frac{\dot{\Pi}^i}{\Pi^i} \right]}, \qquad \text{for } i = A, E. \qquad (17)$$

Thus, the value of the firm is determined by appropriately discounting the instantaneous profit flow of the leader firm using the market interest rate, the replacement rate and the growth rate in the value of the firm.

At the steady-state equilibrium, American firms capture leadership from European firms with a probability of innovation $I^{AE}dt$ in a fraction of industries n^E. At the same time European firms capture leadership from American firms with a probability of innovation $I^{EA}dt$ in a fraction of industries n^A. Each country maintains a constant share of industry leadership in the continuum. Hence, the flow of industries America captures from Europe must be equal to the flow of industries Europe captures from America:

$$I^{AE}n^E = I^{EA}n^A .$$

Adding $I^{ii}n^i$ to both sides of the above equation and using $I^i = I^{Ai} + I^{Ei}$ for i = A, E yields respectively:

$$I^{AE}n^E + I^{AA}n^A = I^A n^A, \qquad (18)$$

$$I^{EA}n^A + I^{EE}n^E = I^E n^E. \qquad (19)$$

These equations imply that the aggregate intensity of R&D conducted in America (Europe) must be equal to the worldwide R&D targeted at industries with American (European) leadership.

4.2.4 Labor Market Equilibrium

European less-skilled workers experience unemployment due to the minimum wage legislation in this region. The supply of less-skilled labor is derived by multiplying the employment rate $(1 - u^E)$ by the share of the less skilled in population $\eta^E\theta_0^E N(t)$. The demand for less-skilled labor is calculated by multiplying the fraction of industries with European leadership n^E by the labor demand in each industry $cN(t)/\lambda w_L^*$. Unskilled labor market equilibrium in Europe requires

$$(1 - u^E)\theta_0^E\eta^E = \frac{n^E c}{\lambda w_L{}^*}, \qquad \textbf{LM(E)} \qquad (20)$$

where the LHS represents the supply of less-skilled labor, and the RHS shows the demand for less-skilled labor. American less-skilled workers are always employed due to flexible wages in that country. Converting the superscripts of (20) from E to A and setting $u^A = 0$ gives the less-skilled labor market equilibrium in America

$$\theta_0^A\eta^A = \frac{n^A c}{\lambda w_L{}^*}. \qquad \textbf{LM(A)} \qquad (21)$$

Note that in the skilled labor markets of both countries, wages are flexible; thus, full employment prevails. The demand for skilled labor in country i is calculated by multiplying the aggregate intensity of R&D $I^i n^i$ by the unit labor requirement of R&D adjusted by the difficulty measure $aX(t)$. The supply of skilled labor is given by equation (11). Equilibrium in the skilled labor market implies

$$\frac{(1-\theta_0{}^i)^2\eta^i N(t)}{2} = I^i n^i aX(t), \qquad \text{for } i = A, E, \qquad (22)$$

where the LHS shows the supply of skilled workers and the RHS represents the demand for skilled workers.

4.2.5. Steady-State Equilibrium

The steady-state equilibrium can be identified by focusing on the free-entry conditions.[14] To characterize the equilibrium, start by normalizing the consumption per capita for the world citizen c. Note that at the steady-state equilibrium $r^i = \rho$, and Π grows at a rate of n. Solving for $w_H{}^A$ from (7), Π^A from (17), and I^A from (22), and substituting the resulting expressions into the zero-profit condition (16) using (14) and (15) yields the "free-entry condition for America":

$$\frac{(\lambda-1)}{\lambda\left(\rho+\frac{\phi\eta^A(1-(\theta_0{}^A)^2)}{2akn^A[\theta_0{}^A]}-n\right)}=\frac{\sigma akw_L{}^*}{\theta_0{}^A} . \qquad \textbf{FE(A)}$$

In this equation, n^A is defined as a function of $\theta_0{}^A$ through LM(A). The FE condition implicitly characterizes the equilibrium level of $\theta_0{}^A$ as a function of the parameters of the model. Substituting this value of $\theta_0{}^A$ into LM(A) and TA(A) yields the equilibrium levels of n^A and $w_H{}^A$, respectively. Since the measure of industries equals one, the equilibrium level of n^E is given by $n^E = (1 - n^A)$.

Doing the analogous substitutions, one can simplify the zero-profit condition for Europe. More specifically, solving for $w_H{}^E$ from (8), Π^E from (17), and I^E from (22), and substituting the resulting expressions into (16) using (14) and (15) yields the "free-entry condition for Europe":

$$\frac{(\lambda-1)}{\lambda\left(\rho+\frac{\phi\eta^E(1-(\theta_0{}^E)^2)}{2akn^E}-n\right)}=\frac{\sigma a(1-u^E[\theta_0{}^E,n^E])kw_L{}^*}{\theta_0{}^E} . \qquad \textbf{FE(E)}$$

In this equation, u^E is displayed as a function of θ_0^E and n^E through LM(E). With the equilibrium value of n^E already given, the above equation implicitly defines the equilibrium level of θ_0^E in terms of the parameters. Substituting the resulting values of θ_0^E and n^E into LM(E) and TA(E) yields the equilibrium levels of u^E and w_H^E, respectively.

At the steady-state equilibrium, entrepreneur firms of both countries compete globally to discover higher quality products. Firms may target their research efforts at a domestic or foreign industry. The firm that discovers the next generation product in a particular line becomes the sole manufacturer of that product, sustaining temporary monopoly power in the global market. Equalization of unit costs of production implies the equalization of less-skilled wages between the countries. American workers enjoy the minimum wage rate prevailing in Europe; however, it is the European workers who suffer the consequence of the rigid wage by being exposed to unemployment. In equilibrium, given the fixed minimum wage, the free-entry condition in America determines the distribution of industry leadership between the countries. With its share of leadership fixed, Europe must support the minimum wage by bearing unemployment. Observe that there are two linkages integrating the world economy: equalization of the wage rates for the less skilled and the zero-sum competition to capture leadership in a continuum of industries. The former is also observed in the standard H-O models with factor price equalization, whereas the latter is a unique feature of the models that explicitly incorporate the dynamic growth and R&D structure of the economy.[15]

4.3. Comparative Steady-State Analysis

4.3.1. Changes in the Minimum Wage Rate in Europe

Proposition 1: *An increase in the minimum wage rate in Europe* w_L^*

(i) *increases the unemployment rate in Europe* u^E,

(ii) *decreases the skilled wage premium* w_H^i/w_L^* *in both America and Europe,*

(iii) *increases the share of less-skilled workers in America* θ_0^A*, and decreases the share of less-skilled workers in Europe* θ_0^E*.*

(iv) *decreases the intensity of aggregate R&D in America* $I^A n^A$*, increases the intensity of aggregate R&D in Europe* $I^E n^E$*.*

Proof. See Appendix C.

To uncover the intuition behind the proposition, I start by focusing on the Free-Entry condition of America. The rise in the minimum wage in Europe triggers an increase in the less-skilled wage in America by Lemma 1. The higher w_L* has two opposing effects on the profitability of R&D in America. First, it raises the skilled wage premium required to keep θ_0^A constant. This increases the cost of R&D activity. Second, it reduces the demand for less-skilled labor and increases the level of n^A required to maintain the less-skilled labor market equilibrium. The fall in n^A reduces the intensity of R&D per industry, and thereby prolongs the duration of monopoly power. This augments the rewards from innovating. The net impact is a fall in the profitability of R&D.

To maintain equilibrium, θ_0^A must increase. The adjustment in θ_0^A affects the free-entry condition through *three channels*. First, the fall in R&D profitability reduces the demand for skilled labor, putting downward pressure on the skilled wage premium. This reduces the marginal cost of R&D. Second, the fall in the wage premium induces more individuals to remain less skilled and become manufacturing workers. The reallocation of labor from R&D to manufacturing puts upward pressure on the level of n^A required to maintain the labor market equilibrium. The rise in n^A reduces the intensity of R&D activity per industry. This augments the rewards from innovating. Third, the fall in the aggregate level of R&D activity extends the duration of monopoly power. This increases the rewards from innovating. All three channels work to increase the profitability of R&D.

To analyze the changes in n^A, I focus on the less-skilled labor market equilibrium. The higher $\theta_0{}^A$ increases the supply of less-skilled labor, and the higher w_L* reduces the demand for less-skilled labor. To restore equilibrium the fraction of industries with American leadership n^A must increase. To investigate the change in $w_H{}^A/w_L*$, I use the training arbitrage condition. Since more individuals choose to remain less skilled, the skilled wage premium must decline at the new equilibrium.[16]

Let me now investigate the effects of the higher minimum wage on the European economy. Note that the rise in the proportion of industries with American leadership n^A implies a reduction in the proportion of industries with European leadership n^E. Thus, the adjustments in Europe take place both directly due to the rise in w_L* and indirectly due to the fall in n^E. I start by analyzing the two direct effects of w_L* on the FE condition of Europe. First, the increase in w_L* increases the skilled wage premium for a given $\theta_0{}^E$. This increases the marginal cost of R&D. Second, the increase in w_L* reduces the demand for less-skilled labor. This requires a fall in the employment rate to maintain the labor market equilibrium condition. The decline in $(1 - u^E)$ reduces the skilled wage premium for a given $\theta_0{}^E$. This decreases the marginal cost of R&D. It is easy to verify that the positive and negative effects on the cost of innovation cancel each other. Therefore, to analyze the variation in the profitability of R&D, it is sufficient to investigate the indirect effect generated by the reduction in n^E.

Holding $\theta_0{}^E$ constant, one can show that the decline in n^E alters the profitability of R&D by stimulating two effects. First, it generates a reduction in the demand for less-skilled labor, requiring a fall in the employment rate. The decline in $(1 - u^E)$, in turn, decreases the skilled wage premium that keeps $\theta_0{}^E$ fixed. This reduces the marginal cost of R&D. Second, the fall in n^E raises the intensity of R&D per industry, decreasing the duration of monopoly power. This diminishes the rewards from innovating. The net effect turns out to be an increase in the profitability of R&D.

To maintain equilibrium, θ_0^E must decrease. The fall in θ_0^E affects the free-entry condition by stimulating *three mechanisms*. First, the rise in the profitability of R&D increases the demand for skilled labor, putting upward pressure on the skilled wage premium. This increases the marginal cost of R&D. Second, the higher relative wage rate motivates more individuals to become skilled. This generates an increase in the intensity of aggregate R&D, which in turn reduces the duration of monopoly profits and thereby the rewards from innovating. Third, the reallocation of labor from manufacturing to R&D requires a rise in the employment rate of less-skilled labor. The higher $(1 - u^E)$ puts upward pressure on the skilled wage premium required to maintain the training arbitrage condition. This increases the marginal cost of R&D.

The labor market equilibrium implies that three forces govern the change in the rate of unemployment. The fall in n^E and the rise in w_L* both reduce the demand for less-skilled labor, whereas the fall in θ_0^E reduces the supply of less-skilled labor. It turns out that the decline in demand exceeds the reduction in supply, requiring a rise in the unemployment rate. The training arbitrage condition suggests that the relative wage of skilled labor is subject to two forces. The fall in θ_0^E increases w_H^E/w_L*, whereas the rise in u decreases w_H^E/w_L*. The net impact on the skilled wage premium is negative.[17]

4.3.2. Technological Change in R&D Activity

Proposition 2: *Technological change in R&D in form of a reduction in the unit labor requirement of R&D activity a*

(i) *decreases the unemployment rate in Europe u^E,*

(ii) *increases the skilled wage premium w_H^i/w_L* *for i = A, E, that is in both America and Europe,*

(iii) *decreases the share of less-skilled workers in America θ_0^A, and decreases the share of less-skilled workers in Europe θ_0^E if and only if technology elasticity of European leadership $\varepsilon(n_E, a)$ is less than one.*

(iv) *increases the intensity of aggregate R&D in America $I^A n^A$, increases the intensity of aggregate R&D in Europe $I^E n^E$ if and only if $\varepsilon(n^E, a) < 1$.*

Proof. See Appendix C.

Let me now describe the economic intuition of Proposition 2. Technological change driven by a fall in a has *two opposing effects* on the free-entry condition of America. First, it reduces the amount of labor required for a given level of innovative activity. This decreases the marginal cost of conducting R&D. Second, it a stimulates a higher level of aggregate R&D activity, which reduces the duration of monopoly profits. This diminishes the returns from innovating. The net effect turns out to be an increase in the profitability of R&D activity.

To maintain the free-entry condition, θ_0^A must fall. The reduction in θ_0^A affects the profitability of R&D by the *three channels* identified in the minimum wage analysis. The fall in θ_0^A decreases the supply of less-skilled labor. To restore labor market equilibrium, the fraction of industries with American leadership must decrease, generating a decline in the demand for less-skilled labor. Moreover, the fall in θ_0^A suggests that more individuals have chosen to become skilled. Thus, the skilled wage premium attains a higher level at the new equilibrium.

Let me now turn to investigating the effects of technological change on the European economy. The adjustments in Europe take place both directly due to the fall in a and indirectly via the rise in n^E. The direct adjustment basically operates by triggering the *two opposing effects* on the FE condition identified in the America analysis above. Therefore, the net impact of the direct effect on the profitability of R&D is positive. The indirect adjustment stimulates two forces on the free-entry condition. First, the rise in n^A reduces the R&D intensity per industry, and thereby prolongs the duration of the leader firm. Second, it increases the rate of employment $(1 - u^E)$ required to maintain the labor market equilibrium. The higher $(1 - u^E)$ increases the skilled wage premium that keeps θ_0^A fixed. The net impact of the indirect adjustment on the profitability of R&D is negative.

The overall change in the R&D profitability (generated by the direct and indirect adjustments) depends on the technology elasticity of American industry leadership defined as $\varepsilon(n^E, a) = - (\partial n^E/\partial a)(a/n^E)$. If the European industry leadership with respect to technology is inelastic, then the profitability of R&D increases, resulting in a lower level of θ_0^E, and vice versa. The unemployment rate of less-skilled workers declines regardless of the level of $\varepsilon(n^E, a)$. In the elastic case $\varepsilon(n^E, a) > 1$, the higher n^E increases the demand for less-skilled labor, and the higher θ_0^E increases the supply of less-skilled labor. The demand change dominates the supply change; thus, u must decrease to maintain equilibrium. In the inelastic case $\varepsilon(n_E, a) < 1$, the higher n^E increases the demand for less-skilled, and the lower θ_0^E decreases the supply of less-skilled. Hence, both changes imply that u must decrease to restore equilibrium.

The skilled wage premium increases regardless of the technology elasticity of American leadership. In the inelastic case, the rise in $(1 - u^E)$ increases w_H^E/w_L^*, whereas the rise in θ_0^E decreases w_H^E/w_L^*. The positive effect dominates the negative one, increasing the skilled wage premium. In the elastic case, both the rise in $(1 – u^E)$ and the fall in θ_0^E positively contribute to the skilled wage premium.

4.3.3. Changes in the Distribution of Global Population

Proposition 3: *An increase in the share of Europe in the global population (that is, a rise in η^E)*

(i) *increases the unemployment rate in Europe u^E if and only if the share of European leadership in industries is higher than its share in global population $n^E > \eta^E$,*

(ii) *has no effect on the skilled wage premium in America w_H^A/w^*, and a negative effect on the skilled wage premium w_H^E/w^* in Europe if and only if $n^E > \eta^E$,*

(iii) *has no effect on the share of less-skilled workers in America* θ_0^A*, and a negative effect on the share of less-skilled workers in Europe* θ_0^E *if and only if* $n^E > \eta^E$.

(iv) *has no effect on the intensity of aggregate R&D in America* $I^A n^A$*, and a positive effect on the intensity of aggregate R&D in Europe* $I^E n^E$ *if and only if* $n^E > \eta^E$.

Proof. See Appendix C.

To analyze the results intuitively, I start by focusing on the FE condition of America. Since $\eta^A + \eta^E = 1$ by definition, the rise in η^E triggers a fall in η^A. The lower η^A stimulates a fall in the supply of both skilled and less-skilled labor in America. The former reduces the aggregate intensity of R&D and extends the duration of monopoly power. This increases the profitability of R&D. The latter requires a decrease in the demand for less-skilled labor, which in turn reduces n^A and increases the replacement rate per industry. This diminishes the returns from R&D. It is easy to see that the two effects cancel each other, and R&D profitability remains unchanged. Thus, the skill distribution in America, and therefore the skilled wage premium, remains fixed. To maintain the less-skilled labor market equilibrium with θ_0^A constant, the fraction of industries with American leadership n^A must fall in the same proportion as η^A.

Let me now discuss the European side of the story. The adjustments in Europe occur both directly due to the rise in η^E and indirectly via the rise in n^E. Examining the free-entry and the less-skilled labor market equilibrium conditions suggest that the profitability of R&D depends on the ratio (n^E/η^E). To facilitate the exposition let me explore the case where the (n^E/η^E) ratio falls due to a rise in η^E. This is true if and only if Europe accounts for a disproportionately higher share of leadership compared to its share in the global population, that is $n^E > \eta^E$. In this case, the rise in η^E stimulates a rise in the profitability of R&D, which requires a fall in θ_0^E. The fall in the supply of less-skilled labor requires a fall in the employment rate $(1 - u^E)$ to maintain labor market equilibrium. On the other hand, the fall in the industry leadership share adjusted with population (n^E/η^E) requires a fall in $(1 - u^E)$. The overall impact is a rise in the unemployment rate. The higher level of u puts downward pressure, and the lower level of θ_0^F puts upward pressure on the skilled wage premium required to maintain the training arbitrage. The net effect is a decrease in the relative wage of the less skilled.

4.3.4. Changes in Unemployment Benefits

I introduce unemployment benefits into the model by assuming that jobless workers are eligible to receive a fraction α of the minimum wage, where $\alpha \in (0, 1)$. This enters the model only by altering the training arbitrage condition of Europe as $\theta_0^E = \sigma(1 - u(1 - \alpha))w_L^*/w_H^E$. The unemployment benefits incorporated FE condition of Europe becomes

$$\frac{(\lambda-1)}{\lambda\left(\rho+\frac{\phi\eta^E(1-(\theta_0{}^E)^2)}{2akn^E}-n\right)}=\frac{\sigma a(1-u[\theta_0{}^E,n^E](1-\alpha))kw_L{}^*}{\theta_0{}^E},\quad \textbf{FEB(E).}$$

The FE condition of America and the labor market equilibrium conditions of both countries remain as they are. Proposition 4 summarizes the effects of a rise in α on the global economy.

Proposition 4: *An increase in the unemployment benefit rate* α

(i) *increases the unemployment rate in Europe* u^E,

(ii) *has no effect on the skilled wage premium in America* w_H^A/w^*, *and a negative effect on the skilled wage premium in Europe* w_H^E/w^*,

(iii) *has no effect on the share of less-skilled workers in America* θ_0^A, *and a positive effect on the share of less-skilled workers in Europe* θ_0^E.

(iv) *has no effect on the intensity of aggregate R&D in America* I^An^A, *decreases the intensity of aggregate R&D in Europe* I^En^E.

The proof and the intuition for this proposition is as follows. First, note that since FE(A) and LM(A) remain the same, the distribution of industry leadership between the two countries is unchanged. In America, the relative wage rate and the ratio of skilled to less-skilled labor also remain constant. Turning to Europe, one can see from the above FEB(E) condition that the higher benefit rate increases the skilled wage premium required to maintain the arbitrage condition. This increases the marginal cost of innovative activity. To maintain the zero-profit in R&D condition, θ_0^E must increase. This increases the profitability of R&D by the three mechanisms identified in the minimum wage analysis. On the other hand, the higher level of θ_0^E expands the supply of less-skilled labor. To maintain labor market equilibrium with a constant level of demand for labor, the unemployment rate must increase. The increased levels of u^E and θ_0^E both imply that the relative wage rate of skilled labor attains a higher level at the new equilibrium.

4.4. Conclusion

This chapter explored the effects of global shocks in a two country setting, where minimum wage legislation in one country generates unemployment in that country. The existing models incorporating minimum wage to generate unemployment mostly use Heckscher-Ohlin frameworks, ignoring issues like endogenous R&D, innovation, and growth. The main contribution of this chapter is that it analyzes the effects of global shocks on labor markets as well as on the rates of innovation and growth. The model establishes several novel comparative steady-state results including adjustments in the minimum wage rate, technological change in R&D and manufacturing, changes in the distribution of the global population across countries, and variations in unemployment benefits.[18] The simple model developed in this chapter can be extended in various directions by introducing newly industrialized countries into the picture, or allowing for substitutability of labor in manufacturing and R&D.

4.5. Notes

[1] Nickell (1997) and Siebert (1997) provide extensive overviews on the causes of diverse labor market developments between U.S. and Europe, focusing on the role of institutional differences.

[2] See Freeman (1995) on the role of demand shifts in explaining the differences between America and Europe regarding labor markets.

[3] See Freeman and Katz (1995), Krugman (1995), and Bertalo and Ichino (1995).

[4] More specifically, Brecher (1974) introduces minimum-wage restriction to the standard two-country Heckscher-Ohlin model of trade and studies optimal trade policies and welfare implications. Building on this work, Davis (1998) considers a flexible-wage America and a minimum-wage Europe. He investigates the effects of three exogenous events on the labor markets: opening of trade between the two regions, entry of a third region (the less-skilled abundant South), and migration from South to North. Using a similar model, Davis (1999) analyzes the effects of global technological change on relative wages and unemployment.

[5] In a recent study, Katz et al. (1995) argue that cross-country differences in the evolution of relative factor supplies (between skilled and less-skilled labor) can account for the observed changes in wage income inequality. Their analysis treats the changes in the relative supplies as exogenous. Davis and Reeve (1997) point out that allowing for endogenous human capital formation can provide some alternative explanations. The present model incorporates endogenous skill acquisition of individuals in the same spirit as Davis and Reeve (1997).

[6] Lawrence and Slaughter (1993), and Sachs and Shatz (1994) empirically investigated this issue. The first study found no change in the relative price of less-skilled intensive commodities, whereas the second study found a small relative price decline.

[7] Dinopoulos and Segerstrom (1999) argue that by producing superior products Europe and Japan challenged the competitiveness of U.S. industries (e.g. semiconductors, automobiles, machine tools etc.) in the 1980s.

[8] See the second chapter of the dissertation for empirical support on the assumed dual labor market structure.

[9] This condition is equivalent to maximization of the family's discounted utility. See DS (1999) for details.

[10] The skilled workers, of course, can be employed in manufacturing. However, a skilled worker with an ability level $\theta > \theta_0$ always chooses to work in R&D if she is offered the fixed manufacturing wage otherwise. The reason is that her expected discounted income stream by working in R&D is higher than the income stream by working in manufacturing [i.e., equation (5) holds]. The marginal individual with ability level θ_0^i is different between manufacturing and R&D activity.

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[11] Grossman and Helpman (1991b) provide this argument in a knowledge-based model of trade with flexible wages and fixed skill distribution. Their model allows for substitutability of skilled and less-skilled labor in R&D and manufacturing.

[12] With this specification, policy-related exogenous parameter changes have "permanent effects on growth". Therefore, it is called the PEG specification. The PEG specification is proposed by Dinopoulos and Thompson (1996). Dinopoulos and Thompson (1998) provide micro foundations for this specification in the context of a model with horizontal and vertical product differentiation.

[13] At each instant in time *a typical* R&D firm j in country i targeting an industry ω chooses the level of R&D intensity according to the production function $I_j^i(\omega,t) = H_j^i(\omega,t)/X(\omega,t)a^i$, where $I_j^i(\omega,t)$ denotes the probability of discovering the next higher quality product, and $H_j^i(\omega,t)$ shows the level of skilled labor employed. The *typical* firm in an R&D race maximizes the expected discounted profits

$$\Pi^i(\omega,t)\, I_j^i(\omega,t)dt - w_H^i(\omega,t)\, H_j^i(\omega,t)dt,$$

where $\Pi^i(\omega,t)$ represents the expected discounted profits of a *successful* innovator in country i. Firm j enjoys Π^i with the instantaneous probability $I_j^i(\omega,t)dt$ and incurs the cost $w_H^i(\omega,t)H_j^i(\omega,t)dt$. Free entry into R&D races implies that the above expression must be equal to zero. The ω terms drop out in a symmetric equilibrium in which the intensity of R&D targeted at the industries of country i is the same.

[14] The existence and uniqueness of the steady-state equilibrium is established in Appendix C.

[15] See Grossman and Helpman (1991b) for an exposition of the models focusing on the effects of innovation and R&D on the patterns of trade.

[16] Alternatively, one can investigate the changes in the *observed* average relative wage of skilled labor, $(1 + \theta_0)w^H/2w^*$. In all cases (except for Propositions 2 and 3), the *observed* average relative wage moves in the same direction as the relative wage measured in *efficiency* units w^H/w^*.

[17] It is straightforward to show that the qualitative effects of exogenous labor-saving technological change in manufacturing (i.e., a reduction in b) are identical to those of an increase in the minimum-wage rate. Moreover, opening of trade between America and Europe also generates the effects outlined in Proposition 1, if in autarky both countries are identical except for their labor markets, and Europe enjoys a higher less-skilled wage compared to America.

[18] One can compare some results of the model regarding wages and unemployment with those of Davis and Trevor (1997). The predictions of the paper on opening of trade between a flexible-wage America and a minimum-wage Europe are identical to those of Davis and Trevor (1997) [see endnote 17]. However, the results on the effects of an increase in one country's share in global population differ markedly. The main difference that gives rise to this discrepancy lies in the modeling of skill acquisiton. Davis and Trevor (1997) follow the Findlay and Kierzkowski (1983) analysis and do not incorporate ability levels of individuals [see Borsook (1987)] into the mechanism. Their modeling has the undesirable feature that, for instance, if the size of population in America increases, all of the additional population enter the

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labor force as less-skilled workers. Moreover, they found that "increases in population regardless of location increase unemployment in Europe." Their model allows them to analyze increases in the population size of each region in isolation. On the contrary, in the present model, the wage and unemployment rates can only be affected by a variation in one country's *share* in global population as opposed to a variation in its *size* of population.

APPENDIX A
PROOFS OF PROPOSITIONS IN CHAPTER 2

A.1. Proof of Proposition 1: Existence and Uniqueness of the Steady-State Equilibrium

A.1.1. Step 1

Using equations (19), (21) and the labor flow identity $q(v_i)v_i = p(v_i)$, one can eliminate the $(I + \beta)(1 - u_{iS})$ terms and derive

$$n/(q(v_i)) = (e^{ny} - 1), \qquad \text{for } i = H, L. \tag{A.1}$$

Equation (A.1) can be solved for a unique value of $v^* = v_L = v_H$ under the assumptions regarding the matching function. Note that it is homogenous of degree one, concave and exhibits positive marginal products. Moreover, it is assumed that $q(0) = p(\infty) = \infty$, $q(\infty) = p(0) = 0$, and $p(v_i) > 0$ for all v_i.

A.1.2. Step 2

Having determined a strictly positive unique value for v^*, the next step is to plot the FEC and LMC curves. First, I identify the region in which the amounts of less-skilled and skilled labor available for manufacturing are strictly positive; that is $(1 - s - B_L xI) > 0$ and $(s - B_H xI) > 0$. I assume that the following properties hold for the standard unit cost functions:

$$1.\ w_L \rightarrow 0 \Rightarrow A_L(w_L, w_H) \rightarrow \infty,\ A_H(w_L, w_H) \rightarrow 0; \tag{A.2}$$

$$w_L \rightarrow 0 \Rightarrow B_L(w_L, w_H) \rightarrow \infty,\ B_H(w_L, w_H) \rightarrow 0$$

$$2.\ A_{LH}(w_L, w_H) = A_{HL}(w_L, w_H) > 0,\ A_{LL}(w_L, w_H) < 0; \tag{A.3}$$

$$B_{LH}(w_L, w_H) = B_{HL}(w_L, w_H) > 0,\ B_{HH}(w_L, w_H) < 0$$

Under the above assumptions, the shaded areas in Figures A-1 and A-2 identify the feasible labor allocation region for the PEG and TEG models, respectively. CL represents the loci of

(I, w_L) points for which the whole less-skilled labor force is absorbed by the R&D sector (i.e., $1 - s = B_L x I$). Similarly CH displays the loci of (I, w_L) points for which the whole skilled labor force is employed by R&D (i.e., $s = B_H x I$). The unique intersection of CL and CH corresponds to the case in which the economy completely specializes in R&D. In Figure A-1, I^{max} denotes the maximum attainable level of R&D for the PEG model, and in Figure A-2, x^{max} denotes the maximum attainable relative R&D difficulty for the TEG model.

For future use let me totally log differentiate the FEC and LMC equations

$$\begin{bmatrix} FEC_I & FEC_x & FEC_{w_L} \\ LMC_I & LMC_x & LMC_{w_L} \end{bmatrix} \begin{bmatrix} dI \\ dx \\ dw_L \end{bmatrix} = \begin{bmatrix} FEC_\lambda & FEC_s \\ 0 & LMC_s \end{bmatrix} \begin{bmatrix} d\lambda \\ ds \end{bmatrix}, \tag{A.4}$$

where subscripts refer to partial derivatives. Using the standard properties of the unit cost functions and the assumption that R&D is skilled labor intensive relative to manufacturing $(B_H/B_L) > (A_H/A_L)$, it is possible to sign the matrix terms in the feasible labor allocation region as follows:

$$FEC_I = \frac{1}{(I+\beta)} + \frac{B_L x}{(1-s-B_L xI)} + \frac{1}{(\rho+I-n)} > 0$$

$$FEC_x = \frac{(1-s)}{x(1-s-B_L xI)} > 0$$

$$FEC_{w_L} = \frac{(B_L A_H - B_H A_L)}{A_H B} + \frac{(A_{LL} A_H - A_{LH} A_L)}{A_H A_L} + \frac{xI(B_{LL} A_H - B_{LH} A_L)}{A_H(1-s-B_L xI)} < 0$$

$$FEC_\lambda = \frac{1}{(\lambda-1)} > 0$$

$$FEC_S = -\frac{1}{(1-s-B_L xI)} < 0$$

$$LMC_I = \frac{x(B_H(1-s)-B_L s)}{(1-s-B_L xI)(s-B_H xI)} > 0$$

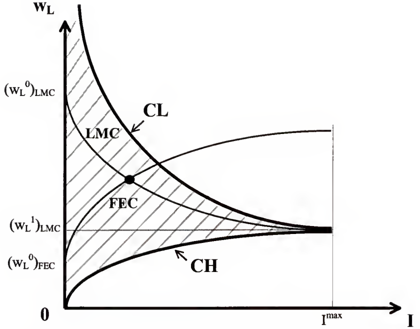

Figure A-1: The Feasible Resource Allocation Set (The PEG Model)

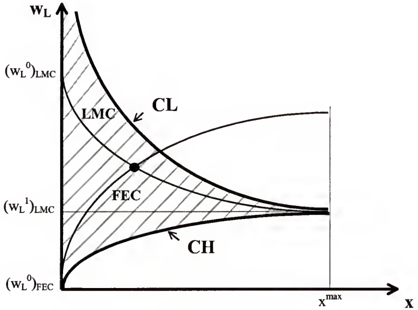

Figure A-2: The Feasible Resource Allocation Set (The TEG Model)

$$\mathrm{LMC}_x = \frac{I(B_H(1-s)-B_L s)}{(1-s-B_L xI)(s-B_H xI)} > 0$$

$$\mathrm{LMC}_{w_L} = -\frac{xI(B_{LL}A_H - B_{LH}A_L)}{A_H(1-s-B_L xI)} + \frac{xI(B_{HL}A_H - B_{HH}A_L)}{A_H(s-B_H xI)} - \frac{(A_{LL}A_H - A_{LH}A_L)}{A_H A_L} + \frac{(A_{HL}A_H - A_{HH}A_L)}{(A_H)^2} > 0$$

$$\mathrm{LMC}_s = \frac{[1-(B_L+B_H)xI]}{(1-s-B_L xI)(s-B_H xI)} > 0 .$$

A.1.3. Step 3

A.1.3.1. The PEG Model

In the feasible labor allocation region of (I, w_L) span, it follows that

$\left.\frac{dw_L}{dI}\right|_{FEC} = -\frac{FEC_I}{FEC_{w_L}} > 0$, and $\left.\frac{dw_L}{dI}\right|_{LMC} = -\frac{LMC_I}{LMC_{w_L}} < 0$. Thus, both FEC and LMC establish a monotonic relationship between I and w_L. To analyze the LMC curve, first note that for any finite wage level w_L the labor market equilibrium conditions must be satisfied [see Bhagwati and Srinisavan (1983), p.62]. Hence, I can proceed by assuming finite values for w_L. On the LMC curve if $I = 0$, then $(1 - s)/s = A_L/A_H$ defines $(w_L^0)_{LMC}$; and if $I = I^{max}$ then $(1 - s)/s = B_L/B_H$ defines $(w_L^1)_{LMC}$. To see this rewrite the LMC equation as follows

$$\frac{(1-s)}{s} = \frac{B_L}{B_H}\psi + \frac{A_L}{A_H}(1-\psi), \qquad \mathbf{LMC'}$$

where $\psi = B_H xI/s$. Thus, LMC′ becomes identical to the factor-endowment ratio identity in the standard Heckscher-Ohlin model [see Bhagwati and Srinisavan (1983), pp: 62-65]. Complete specialization in R&D implies that $\psi = 1$ and $(1 - s)/s = B_L/B_H$, whereas complete specialization in manufacturing dictates that $\psi = 0$ and $(1 - s)/s = A_L/A_H$. The interval $((w_L^0)_{LMC},\ (w_L^1)_{LMC})$ identifies the feasible values of w_L for which there is incomplete specialization. On the FEC curve, if $I = 0$ then $B(w_L)A(w_L) = K/\beta(\rho - n)\phi$ defines $(w_L^0)_{FEC}$, where $K = e^{-\rho y}p(v^*)(\lambda - 1)$. Any level of $w_L < (w_L^0)_{FEC}$ implies that rewards for innovating becomes less than its marginal cost; hence, innovative activity stops, i.e., $I = 0$. Note that the FEC curve must lie above CL for

$\infty > I > 0$ and $\infty > w_L > 0$. To see this suppose the FEC curve intersects with the CL curve in the specified region. Substituting the CL relationship $(1 - s - B_L xI) = 0$ into FEC implies that the expected returns to innovation must be equal to zero; hence, $xI = \phi I = 0$ must hold, which is a contradiction. The conditions stated in Assumption 3 (λ being sufficiently high; ρ and ϕ being sufficiently low) guarantee that $(w_L{}^0)_{LMC} > (w_L{}^0)_{FEC}$. With FEC curve upward sloping and lying above CL, LMC curve downward sloping, and $(w_L{}^0)_{LMC} > (w_L{}^0)_{FEC}$, I conclude that a unique equilibrium exists in the strictly positive orthant as illustrated in Figure A-1.

A.1.3.2. The TEG Model

In the feasible labor allocation region of (x, w_L) span, it follows that

$\left.\dfrac{dw_L}{dx}\right|_{FE} = -\dfrac{FE_x}{FE_{w_L}} > 0$, and $\left.\dfrac{dw_L}{dx}\right|_{LM} = -\dfrac{LM_x}{LM_{w_L}} < 0$. The monotonic relationship between I and w_L for each condition implies that w_L can be defined implicitly as a function of I through FEC and LMC. Similar arguments to those outlined in the PEG model can be used to derive the end point values of the LMC curve. Using LMC′ one can show that if $x = 0$ then $(1 - s)/s = A_L/A_H$ defines $(w_L{}^0)_{LMC}$; if $x = x^{max}$, then $(1 - s)/s = B_L/B_H$ defines $(w_L{}^1)_{LMC}$. To analyze the FEC curve first substitute $I = n/\mu$ into FEC and express x as a function of w_L.. This yields

$$x = \frac{K^*(1-s)}{A_L B + (K^* n/\mu)B_L} \qquad \textbf{FEC}$$

where $K^* = e^{-\rho y}p(v^*)(\lambda - 1)/\{[\rho + (n/\mu) - n][(n/\mu) + \beta)]\}$ is a positive constant. On the FEC curve if $x = 0$ then the denominator on the RHS should go to infinity. Since for a finite value of w_L the denominator attains a finite value, we need to consider two possibilities which are $w_L \rightarrow \infty$ or $w_L \rightarrow 0$. First, I analyze whether $x \rightarrow 0$ and $w_L \rightarrow \infty$ satisfy FEC. With the FEC curve upward sloping in the feasible labor reallocation region, this renders the FEC function undefined for any finite value of w_L in the feasible region. Ruling out this possibility requires that as $w_L \rightarrow \infty$, $\lim A_L B \neq \infty$ (since as $w_L \rightarrow \infty$, the second term in the denominator $B_L \rightarrow 0$;

hence, no restriction is required on B_L). This requirement holds for Cobb-Douglas production functions. Next, I analyze whether $x \to 0$ and $w_L \to 0$ satisfies FEC. Note that as $w_L \to 0$, $B_L \to \infty$; thus, when $A_L B \geq 0$ (which holds by assumption) the denominator in FEC goes to infinity. Therefore, I conclude that on the FEC curve as $x \to 0$, $w_L \to 0$ holds under the assumption that as $w_L \to \infty$, $\lim A_L B \neq \infty$. Moreover, note that the FEC curve lies above CL for $\infty > x > 0$ and $\infty > w_L > 0$. To see this suppose that FEC intersects with CL in the specified region. Substituting CL relationship $(1 - s - B_L xI) = 0$ into FEC implies that returns to innovation must be equal to zero; hence, innovation stops and $xI = x(n/\mu) = 0$ must hold, which is a contradiction. With FEC curve upward sloping and lying above CL curve, LMC curve downward sloping, and $(w_L{}^0)_{LMC} > (w_L{}^0)_{FEC}$ (since $(w_L{}^0)_{FEC} \to 0$), I conclude that a unique equilibrium exists in the strictly positive orthant in Figure A.2.

A.2. Proof of Proposition 2: Comparative Steady-State Results for an increase in λ

To derive the comparative steady-state results, I utilize the Jacobian matrix (A.4). First, consider the PEG model; where $x = \phi$ and $dx = 0$. The determinant of the Jacobian matrix $\Delta^{PEG} = FEC_I LMC_{WL} - FEC_{WL} LMC_I > 0$. Using Cramer's rule, I derive the following:

$$\frac{dI}{d\lambda} = \frac{FEC_\lambda LMC_{w_L}}{\Delta^{PEG}} > 0 \qquad \text{(A.5)}$$

$$\frac{dw_L}{d\lambda} = -\frac{FEC_\lambda LMC_I}{\Delta^{PEG}} < 0. \qquad \text{(A.6)}$$

To derive changes in w_H, u_R and u_A, I follow a more general approach and denote with $d\tau$ an exogenous parameter change. To analyze variations in w_H totally differentiating $A(w_L, w_H) = 1$ with respect to τ yields

$$\frac{dw_H}{d\tau} = -\frac{A_L}{A_H}\frac{dw_L}{d\tau}. \qquad \text{(A.7)}$$

To find changes in u_R, totally differentiating $u_R = A_L/A_H$ with respect to τ yields

$$\frac{du_R}{d\tau} = \frac{du_R}{dw_L}\frac{dw_L}{d\tau} \tag{A.8}$$

where $du_R/dw_L < 0$. To investigate changes in u_A, totally log differentiating $u_A = u_S[1 - xI(B_L + B_H)]$ with respect to τ gives

$$\begin{aligned}\frac{du_A}{d\tau}\frac{1}{u_A} = {} & \frac{du_S}{dI}\frac{1}{u_S}\frac{dI}{d\tau} - \frac{x(B_L + B_H)}{[1 - xI(B_L + B_H)]}\frac{dI}{d\tau} - \frac{I(B_L + B_H)}{[1 - xI(B_L + B_H)]}\frac{dx}{d\tau} \\ & - \frac{1}{[1 - xI(B_L + B_H)]}\frac{d(B_L + B_H)}{dw_L}\frac{dw_L}{d\tau}\end{aligned} \tag{A.9}$$

where $du_S/dI > 0$ and $d(B_L + B_H)/dw_L < 0$ (see Proposition 3). Note that changes in the aggregate unemployment rate consists of four terms. The first term shows the creative destruction effect, the rest of the terms together represent the resource reallocation effect.

I now proceed by substituting for $d\tau = d\lambda$ into (A.7), (A.8) and (A.9). Using (A.5) and (A.6) I derive the following

$$\frac{dw_H}{d\lambda} > 0,\ \frac{du_R}{d\lambda} > 0,\ \frac{du_A}{d\lambda} \gtrless 0. \tag{A.10}$$

Next, I consider the TEG model where $I = n/\phi$ and $dI = 0$. The determinant of the Jacobian matrix is $\Delta^{TEG} = FEC_X LMC_{WL} - FEC_{WL} LMC_x > 0$. Using Cramer's Rule one can derive

$$\frac{dx}{d\lambda} = \frac{FEC_\lambda LMC_{w_L}}{\Delta^{TEG}} > 0 \tag{A.11}$$

$$\frac{dw_L}{d\lambda} = -\frac{FEC_\lambda LMC_I}{\Delta^{TEG}} < 0\,. \tag{A.12}$$

Substituting for $d\tau = d\lambda$ into (A.7), (A.8) and (A.9) using the results in (A.11) and (A.12) yields

$$\frac{dw_H}{d\lambda} > 0,\ \frac{du_R}{d\lambda} > 0,\ \frac{du_A}{d\lambda} < 0.$$

A.3. Proof of Proposition 3: Comparative Steady-State Results for an increase in s

For the PEG model using (A.4) and Cramer's rule, I obtain

$$\frac{dI}{ds} = \frac{FE_S LMC_{WL} - FE_{WL} LMC_S}{\Delta^{PEG}} > 0 \tag{A.13}$$

$$= -\frac{1}{\Delta^{PEG}(1-s-B_L xI)}\left[\frac{1}{(s-B_H xI)}\frac{d(B_L+B_H)}{dw_L} + \frac{1}{A_H}\frac{d(A_L+A_H)}{dw_L} + \frac{(B_L A_H - B_H A_L)(A_H + A_L)}{B(A_H)^2}\right]$$

Hence, $\frac{dI}{ds} > 0$ if $\frac{d(B_L + B_H)}{dw_L} < 0$ and $\frac{d(A_L + A_H)}{dw_L} < 0$ (see Proposition 3). These conditions are satisfied for Cobb-Douglas production functions if and only if $w_H > w_L$, and for CES functions if w_H is sufficiently larger than w_L. Moreover,

$$\frac{dw_L}{ds} = \frac{FEC_I LMC_s - FEC_S LMC_I}{\Delta^{PEG}} > 0. \tag{A.14}$$

Substituting for $d\tau = ds$ into (A.7), (A.8) and (A.9) using (A.13) and (A.14) yields

$$\frac{dw_H}{ds} < 0,\ \frac{du_R}{ds} < 0,\ \frac{du_A}{ds} \gtrless 0. \tag{A.15}$$

Next, I consider the TEG model. Using Cramer's rule it follows that

$$\frac{dx}{ds} = \frac{FEC_S LMC_{WL} - FEC_{WL} LMC_S}{\Delta^{TEG}} > 0. \tag{A.16}$$

Note that the numerator of dx/ds is identical to that of dI/ds the PEG model; hence, I conclude that $\frac{dx}{ds} > 0$ if $\frac{d(B_L + dB_H)}{dw_L} < 0$ and $\frac{d(A_L + A_H)}{dw_L} < 0$. Moreover,

$$\frac{dw_L}{ds} = \frac{FEC_x LMC_s - FEC_S LMC_x}{\Delta^{TEG}} > 0. \tag{A.17}$$

Substituting for $d\tau = ds$ into (A.7), (A.8) and (A.9) using the results in (A.16) and (A.17) give

$$\frac{dw_H}{ds} < 0,\ \frac{du_R}{ds} < 0,\ \frac{du_A}{ds} \gtrless 0. \tag{A.18}$$

APPENDIX B
PROOFS OF PROPOSITIONS IN CHAPTER 3

B.1. Steady-State Equations

The analysis focuses on the range of values for the endogenous variables where u, $\theta_0 \in (0, 1)$ and $x > 0$. Let me restate the RD and LM equations and express θ_0 as a function of u and x for each condition.

$$\theta_0(x, u) = \left[\frac{a\sigma x e^{\rho y}(\rho + 2I(u) - n)}{K(\tau)}\right]^{1/2}, \qquad \textbf{RD}$$

$$\theta_0(x, u) = \left[1 - \frac{ak}{\phi}\left(\frac{p(v^*)}{1-u} - \beta\right)\right]^{1/2}. \qquad \textbf{LM}$$

B.2. Proofs of Propositions 1, 2 and 4 for the PEG Specification

B.2.1. Proposition 1

In the PEG model, we need $a\sigma k e^{\rho y}(\rho - n + p(v^*) - \beta)/K(\tau) < 1 - [ak(p(v^*) - \beta)/\phi]$ as a sufficient condition to obtain unique equilibrium values for the endogenous variables in the specified range. The LHS above inequality represents the vertical intercept of the RD curve and the RHS defines that of the LM curve. To see this, start by substituting the PEG specification $x = k$ into RD and LM, and obtain a system of two equations with two unknowns θ_0 and u. Totally differentiating the resulting system yields

$$\begin{bmatrix} RD_\theta & RD_u \\ LM_\theta & LM_u \end{bmatrix}\begin{bmatrix} d\theta_0 \\ du \end{bmatrix} = \begin{bmatrix} RD\tau \\ 0 \end{bmatrix}[d\tau], \qquad \text{(B.1)}$$

where $RD_\theta = 2/\theta_0 > 0$, $RD_u = -p(v^*)/[(1 - u)^2(\rho - n + [p(v^*)/(1 - u)] - \beta)] < 0$,

$RD_\tau = \lambda/(1+\tau)^2K(\tau) > 0$, $LM_\theta = 2\theta_0 > 0$, $LM_u = kap(v^*)/[\phi(1-u)^2] > 0$, and the determinant of the Jacobian matrix $\Delta = RD_\theta LM_u - RD_u LM_\theta > 0$.

The slope of the RD curve in (u, θ_0) space is given by $\left.\frac{d\theta_0}{du}\right|_{RD} = -\frac{RD_u}{RD_\theta} > 0$. On the RD curve as $u \rightarrow 1$, $\theta_0 \rightarrow \infty$, but $\theta_0 < 1$ must hold; thus RD curve becomes flat at $\theta_0 = 1$, and u_{RD} satisfies $\theta_0(u_{RD}) = 1$. Intuitively, when $\theta_0 = 1$, innovative activity stops and firms cannot break even (that is; the relative price of innovation becomes less than its marginal cost). Higher levels of $u \in (u_{RD}, 1)$ simply contributes adversely to the price marginal cost differential. Thus, for $\theta_0 = 1$ the values of $u \in (u_{RD}, 1)$ satisfy the RD condition by further reducing the profitability of innovation. Moreover, on the RD curve as $u \rightarrow 0$, $\theta_0 \rightarrow (\theta_0)_{RD}$, where $(\theta_0)_{RD} = [a\sigma k e^{\rho y}(\rho - n + p(v^*) - \beta)/K(\tau)]^{1/2}$.

Turning now to the LM equation, one can sign the slope of LM curve in (u, θ_0) space by $\left.\frac{d\theta_0}{du}\right|_{LM} = -\frac{LM_u}{LM_\theta} < 0$. On the LM curve as $u \rightarrow 0$, $\theta_0 \rightarrow (\theta_0)_{LM} = [1 - (ak(p(v^*) - \beta)/\phi)]^{1/2}$. In addition as $u \rightarrow u_{LM} = 1 - [p(v^*)/((\phi/ka) + \beta)]$, $\theta_0 \rightarrow 0$. Given the assumptions it follows that $0 < (\theta_0)_{RD} < (\theta_0)_{LM} < 1$. Plotting the RD and LM curves in (u, θ_0) span, I conclude that a unique intersection exists as is illustrated in Figure 3-1.

B.2.2. Proposition 2

Using the system of equations given by (B.1), I establish the comparative steady-state results for the PEG specification:

$$\frac{d\theta_0^*}{d\tau} = \frac{RD_\tau LM_u}{\Delta} > 0, \tag{B.3}$$

$$\frac{du^*}{d\tau} = \frac{-RD_\tau LM_{\theta_0}}{\Delta} < 0. \tag{B.4}$$

Since $\frac{w}{1-u} = \frac{\sigma}{\theta_0}$ by equation (6), (B.3) implies $\frac{d(w^*/(1-u^*))}{d\tau} < 0$. To analyze the changes in $u_A = u\theta_0$, totally differentiate u_A and obtain $du_A = ud\theta_0 + \theta_0 du$. Substituting for $d\theta_0^*$ from (B.3) and du^* from (B.4), and using LM yields

$$\frac{du_A{}^*}{d\tau} = \frac{RD_\tau ak}{\Delta\phi}\left[2\left(\frac{p(v^*)}{(1-u^*)} - \beta - \frac{\phi}{ak}\right) + \frac{\phi u^* p(v^*)}{(1-u^*)^2}\right], \tag{B.5}$$

the sign of which depends on the bracketed expression. Note that since $p(v^*) - \beta < (\phi/ka)$ is assumed for existence, for $u = 0$ it $\frac{du_A{}^*}{d\tau} < 0$. For $u = u_{LM}$, which is assumed to be the maximum attainable equilibrium level of u, $\frac{du_A{}^*}{d\tau} > 0$. Moreover, the bracketed expression is increasing in the domain $u \in (0, u_{LM})$. Hence, there exists a critical level of $u = u^C$ which establishes $\frac{du_A{}^*}{d\tau} = 0$.

B.2.3. Proposition 4:

Substituting $c = \lambda(1 - u)\theta_0$ and $I = \frac{1}{2}\left(\frac{p(v^*)}{1-u} - \beta\right)$ into (24) using LM yields

$$F = \frac{1}{(\rho-n)}[\log(1 - u) + ½(\log(1 - \frac{ak}{\phi}2I(u)) + \frac{\log\lambda}{\rho}2I(u)], \tag{B.6}$$

which defines the steady-state welfare in terms of u only. Taking the derivative of (B.6) with respect to τ and equating the resulting expression to zero

$$\frac{dF}{d\tau} = \frac{1}{(\rho-n)(1-u)}\left[-1 - \frac{p(v^*)}{2(1-u)}\left(\frac{2\log\lambda}{\rho-n} - \frac{\xi}{1-2\xi I(u)}\right)\right]\frac{\partial u}{\partial\tau} = 0,$$

(where $\xi = ka/\phi$) characterizes the value of the optimal unemployment rate. The optimal tariff rate, in turn, corresponds to this unemployment rate. Note that u is a monotonically decreasing function of τ. To check the second-order conditions, I investigate the second-order derivative of (B.6) with respect to u and find it to be negative

$$\frac{d^2F}{du^2}=\frac{1}{(1-u^2)(\rho-n)}\left[-1-\frac{p(v^*)}{(1-u)}\left(\frac{\xi}{(1-2\xi I(u))}-\frac{2\log\lambda}{(\rho-n)}\right)-\frac{1}{2}\left(\frac{p(v^*)\xi}{(1-u)^2(1-2\xi I(u))}\right)^2\right]<0,$$

under a sufficient condition $2\log\lambda/(\rho - n) < 1/[(1/\xi) + \beta]$. The above equation will be referred as (B.7).

B.3. Proofs of Propositions 1, 3, and 4 for the TEG Specification:

B.3.1 Proposition 1

To analyze the TEG model, I substitute u* from (23) into RD and LM conditions and obtain a system of two equations with two unknowns θ_0, x. Totally differentiating the resulting system yields

$$\begin{bmatrix} RD_{\theta_0} & RD_x \\ LM_{\theta_0} & LM_x \end{bmatrix}\begin{bmatrix} d\theta_0 \\ dx \end{bmatrix}=\begin{bmatrix} RD_\tau \\ 0 \end{bmatrix}[d\tau], \tag{B.8}$$

where $RD_\theta = 2/\theta_0 > 0$, $RD_x = - 1/x < 0$, $LM_\theta = 2\theta_0 > 0$, $LM_x = na/\mu\phi > 0$, $RD_\tau = \lambda/(1 + \tau)^2 K(\tau)$ and the determinant of the Jacobian $\Delta = RD_\theta LM_x - RD_x LM_\theta > 0$. The slope of the RD curve in (x, θ_0) space is given by $\left.\frac{d\theta_0}{dx}\right|_{RD} = -\frac{RD_X}{RD_\theta} > 0$. On the RD curve as $x \to 0$, $\theta_0 \to 0$. Moreover as $x \to \infty$, $\theta_0 \to \infty$, but $\theta_0 < 1$ must hold. Thus, the RD curve becomes flat at $\theta_0 = 1$, and x_{RD} satisfies $\theta_0(x_{RD}) = 1$. Intuitively, when $\theta_0 = 1$ innovative activity stops and no firm enters into R&D races (that is, the relative price of innovation becomes lower than its marginal cost). Higher levels of $x \in (x_{RD}, \infty)$ basically contributes adversely to the price marginal cost differential. Therefore the set of values of (θ_0, x) where $\theta_0 = 1$ and $x \in (x_{RD}, \infty)$ also satisfy the RD condition.

Turning now to the LM condition, one can sign the slope of the LM curve in (x, θ_0) space as $\left.\frac{d\theta_0}{dx}\right|_{LM} = -\frac{LM_x}{LM_\theta} > 0$. On the LM curve as $x \rightarrow 0$, $\theta_0 \rightarrow 1$, and as $\theta_0 \rightarrow 0$, $x \rightarrow \mu\phi/na$. The vertical intercept of LM is equal to 1 and is higher than that of RD. Plotting the RD and LM curves on (x, θ_0) span, I conclude that a unique intersection exists as is illustrated in Figure 3-2.

B.3.2. Proposition 3

Using the system of equations given by (B.8), I establish the comparative steady-state results for the TEG specification

$$\frac{d\theta_0 *}{d\tau} = \frac{RD_\tau LM_x}{\Delta} > 0, \tag{B.9}$$

$$\frac{dx *}{d\tau} = \frac{-RD_\tau LM_{\theta_0}}{\Delta} < 0. \tag{B.10}$$

Since $\frac{w}{1-u} = \frac{\sigma}{\theta_0}$ by equation (6), (B.9) implies $\frac{d(w*/(1-u*))}{d\tau} < 0$. To investigate the changes in $u_A = u\theta_0$, note that $\frac{du*}{d\tau} = 0$; thus, (B.9) dictates $\frac{du_A*}{d\tau} > 0$.

B.3.3. Proposition 4

Substituting $c = \lambda(1 - u)\theta_0$ and $I = \frac{1}{2}\left(\frac{p(v^*)}{1-u} - \beta\right)$ with $u = u^*$ into (24) and taking the derivative of the resulting expression with respect to τ implies

$$\frac{dF}{d\tau} = \left(\frac{1}{\rho - n}\right)\frac{1}{\theta_0}\frac{\partial\theta_0}{\partial\tau} > 0. \tag{B.11}$$

The sign of $dF/d\tau$ follows from (B.9), which implies $\partial\theta_0/\partial\tau > 0$. Hence, the common tariff rate that maximizes welfare is $\tau = \lambda - 1$.

APPENDIX C
PROOFS OF PROPOSITION IN CHAPTER 4

C.1. Proof of Existence and Uniqueness of the Steady-State Equilibrium

The existence and uniqueness of the steady-state equilibrium follows a graphical approach. First, I analyze the equilibrium values for n^E and u^E. To simplify notation let w* stand for the minimum wage w_L*. Substituting for θ_0^A from LM(A) into FE(A) using $\eta^A = (1 - \eta^E)$ and $n^A = (1 - n^E)$, and then simplifying yields

$$\left(\frac{\lambda-1}{\sigma}+\frac{\phi}{2}\right)=\frac{(1-\eta^E)\lambda^2(w^*)^2}{(1-n^E)}\left((\rho-n)ak+\frac{\phi(1-\eta)}{2(1-n^E)}\right). \qquad \mathbf{n^E} \tag{C.1}$$

Thus, equation (C.1) determines the equilibrium value of n^E. Note that the LHS of (C.1) is a constant, whereas the RHS is increasing in n^E. As $n^E \rightarrow 1$, the RHS $\rightarrow \infty$; and as $n^E \rightarrow 0$, the RHS $\rightarrow$ INT_0, where $INT_0 = (1 - \eta^E)\lambda^2(w^*)^2[(\rho - n)ak + (\phi(1 - \eta^E)/2)]$. Figure C-1 below plots the RHS and the LHS of (C.1) with n^E on the horizontal axis. Hence, the necessary and sufficient condition for the existence and uniqueness of n^E in the domain (0, 1) is

$$\left(\frac{\lambda-1}{\sigma}+\frac{\phi}{2}\right)>(1-\eta^E)\lambda^2(w^*)^2\left((\rho-n)ak+\frac{\phi(1-\eta^E)}{2}\right). \tag{C.2}$$

The next step is to prove that $u^E \in (0, 1)$ exists and is unique. Substituting for θ_0^E from LM(E) into FE(E) yields

$$\left(\frac{\lambda-1}{\sigma}+\frac{\phi}{2}\right)=\frac{\eta^E\lambda^2(w^*)^2(1-u^E)^2}{n^E}\left((\rho-n)ak+\frac{\phi\eta^E}{2n^E}\right) \qquad \mathbf{u^E} \tag{C.3}$$

Thus, equation (C.3) determines the equilibrium value of u^E. Note that the LHS of (C.3) is a constant, whereas the RHS is decreasing in u^E. As $u^E \rightarrow 1$, the RHS $\rightarrow 0$, and as $u^E \rightarrow 0$, the

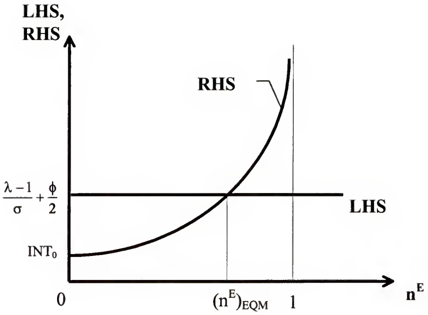

Figure C-1: The Existence and Uniqueness of n^E

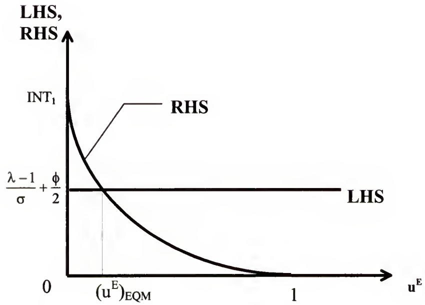

Figure C-2: The Existence and Uniqueness of u^E

RHS → INT_1, where $INT_1 = \eta^E\lambda^2(w^*)^2[(\rho - n)ak + (\phi\,\eta^E/2n^E)]/n^E$. Figure C-2 below plots the RHS and the LHS of (C.3) with u^E on the horizontal axis. Hence, given $n^E \in (0, 1)$ exists and is unique, the necessary condition for the existence and uniqueness of u^E in the domain (0, 1) is

$$\left(\frac{\lambda-1}{\sigma}+\frac{\phi}{2}\right)<\frac{\eta^E\lambda^2(w^*)^2}{n^E}\left((\rho-n)ak+\frac{\phi\eta^E}{2n^E}\right). \tag{C.4}$$

Thus, the necessary and sufficient condition for obtaining unique values for *both* θ_0^E and u^E in the domain (0, 1) requires that (C.2) and (C.4) hold simultaneously. A sufficient condition that satisfies this is η being sufficiently high. Once the unique values for n^E, n^A and u^E are determined, substituting these back into TA(i) and LM(i) gives θ_0^i and w_H^i for i = A, E.

C.2. Proofs of Comparative Steady-State Analysis

To prove the comparative steady-state results, in addition to (C.1) and (C.2), I introduce three more equations. Substituting for n^A from LM(A) into FE(A) gives

$$\frac{(\lambda-1)}{\sigma}=\frac{1}{\theta_0{}^A}\left(\lambda(\rho-n)akw^*+\frac{\phi b}{2\theta_0{}^A}(1-(\theta_0{}^A)^2)\right), \qquad \theta_0^A \tag{C.5}$$

which determines the equilibrium level of θ_0^A. Similarly, substituting for (1 - u) from LM(E) into FE(E) gives

$$\frac{(\lambda-1)}{\sigma b}=\frac{1}{(\theta_0{}^E)^2}\left((\rho-n)ak\left(\frac{n^E}{\eta^E}\right)+\frac{\phi}{2}(1-(\theta_0{}^E)^2)\right) \qquad \theta_0^E \tag{C.6}$$

which characterize the equilibrium level of θ_0^E as an increasing function of n^E. Let $\omega^i = w_H^i/w^*$ represent the skilled wage premium for i = A, E. To analyze changes in ω^E, I substitute w_H^E for $\sigma(1 - u)w_L^*/\theta_0^E$ in FE(E) and derive

$$\omega^E=\frac{(\lambda-1)}{w_L{}^*\lambda\left((\rho-n)ak+\phi(1-(\theta_0{}^E)^2)\left(\frac{\eta^E}{n^E}\right)\right)}, \qquad \omega^E \tag{C.7}$$

which defines the ω^E as an increasing function of θ_0^E and n^E.

C.2.1. Proof of Proposition 1: Changes in the Minimum Wage Rate

Totally differentiating (C.1) gives $\frac{dn^E}{dw_L*} < 0$. Given $n^E = n^E(w_L*)$ by (C.1), I totally differentiate (C.3) and derive

$$\frac{du}{dw*} = \underbrace{\frac{\partial u}{\partial n^E}\frac{dn^E}{dw*}}_{+} + \underbrace{\frac{\partial u}{\partial w*}}_{+} > 0$$

To analyze the variation in θ_0^i, I totally differentiate (C.5) and (C.6) and obtain

$$\frac{d\theta_0^A}{dw*} > 0, \qquad \frac{d\theta_0^E}{dw*} = \underbrace{\frac{\partial\theta_0^E}{\partial n^E}}_{+}\underbrace{\frac{\partial n^E}{\partial w*}}_{-} < 0.$$

Note that the aggregate R&D intensity level $I^i n^i$ is negatively related to θ_0^i through TA(i) for i = A, E. In addition, ω^A is negatively related to θ_0^A. To analyze the change in ω^E, I totally differentiate (C.7) and derive

$$\frac{d\omega^E}{dw*} = \underbrace{\frac{\partial\omega^E}{\partial w*}}_{-} + \underbrace{\frac{\partial\omega^E}{\partial n^E}}_{+}\underbrace{\frac{dn^E}{dw*}}_{-} + \underbrace{\frac{\partial\omega^E}{\partial\theta_0^E}}_{+}\underbrace{\frac{d\theta_0^E}{dw*}}_{-} < 0.$$

C.2.2. Proof of Proposition 2: Technological Change in Activity

Totally differentiating (C.1) gives $\frac{dn^E}{da} < 0$. Given $n^E = n^E(a)$ by (C.1), I totally differentiate (C.3) and obtain

$$\frac{du^E}{da} = \underbrace{\frac{\partial u^E}{\partial n^E}}_{-}\underbrace{\frac{dn^E}{da}}_{-} + \underbrace{\frac{\partial u^E}{\partial a}}_{+} > 0.$$

To analyze the change in θ_0^A, I totally differentiate (C.5) and derive $\frac{d\theta_0^A}{da} > 0$. To investigate the adjustment in θ_0^E, by totally differentiating (C.6), one can show that

$$\text{sign}\frac{d\theta_0^E}{da} = \text{sign}\frac{d(an^E)}{da} = \text{sign}\ (1 - \varepsilon(n^E, a)),$$

where $\varepsilon(n^E, a) = -(\partial n^E/\partial a)(a/n^E)$. Thus, $\frac{d\theta_0{}^E}{da} > 0$ if and only if $\varepsilon(n^E, a) < 1$. Note again that aggregate R&D intensity $I^i n^i$ is negatively related to $\theta_0{}^i$ for $i = A, E$. Also, ω^A is negatively related to $\theta_0{}^i$. Turning to ω^E, I totally differentiate (C.7) and derive

$$\frac{d\omega^E}{da} = \underbrace{\frac{\partial\omega^E}{\partial a}}_{-} + \underbrace{\frac{\partial\omega^E}{\partial n^E}}_{+}\underbrace{\frac{dn^E}{da}}_{-} + \underbrace{\frac{\partial w^E}{\partial\theta_0{}^E}\frac{d\theta_0{}^E}{da}}_{-} < 0.$$

Note that the third term in $d\omega^E/da$ is always negative regardless of the measure of elasticity $\varepsilon(n^E, 1)$, since $\theta_0{}^A$ and w^E always move in opposite directions due to a change in a.

C.2.3. Proof of Proposition 3: Changes in the Distribution of Global Population

To prove the third proposition, start by considering a rise in the parameter η. This induces an increase in n^E through (C.1). Note that for (C.1) to hold, the ratio $\frac{(1-\eta^E)}{(1-n^E)}$ must remain constant. Hence $(1 - n^E)$ must change in the same proportion as $(1 - \eta^E)$. Thus $\frac{d(1-n^E)}{(1-n^E)} = \frac{d(1-\eta^E)}{(1-\eta^E)}$, which in turn implies $\frac{dn^E}{d\eta^E} = \frac{(1-n^E)}{(1-\eta^E)} > 0$ and thus $\frac{dn^A}{d\eta^E} < 0$. Since η^E does not enter (C.5), $\theta_0{}^A$ and therefore ω^A remain constant. In Europe, the direction of change depends on the variation in $(n^E)^* = n^E/\eta^E$, where $(n^E)^*$ measures the industry leadership population ratio in Europe. Using the expression for $dn^E/d\eta^E$ above, one can derive that

$$\text{sign}\ \frac{d(n^E)^*}{d\eta^E} = \text{sign}\ (\eta^E - n^E)\ .\ \text{Thus,}$$

$$\frac{d(n^E)^*}{d\eta^E} < 0 \text{ if and only of } n^E > \eta^E.$$

Totally differentiating (C.6) gives

$$\frac{d\theta_0{}^E}{d\eta^E} = \underbrace{\frac{\partial\theta_0{}^E}{\partial(n^E)^*}}_{+}\,\underbrace{\frac{d(n^E)^*}{d\eta^E}}_{-} < 0, \qquad \text{iff} \qquad n^E > \eta^E.$$

To analyze ω^E, I totally differentiate (C.7) and obtain

$$\frac{d\omega^E}{d\eta^E} = \underbrace{\frac{\partial\omega^E}{\partial(n^E)^*}}_{+}\,\underbrace{\frac{d(n^E)^*}{d\eta^E}}_{-} + \underbrace{\frac{\partial\omega^E}{\partial\theta_0{}^E}}_{+}\,\underbrace{\frac{\partial\theta_0{}^E}{\partial(n^E)^*}}_{+}\,\underbrace{\frac{d(n^E)^*}{d\eta^E}}_{-} < 0, \ \text{iff} \qquad n^E > \eta^E.$$

Since ω^E is negatively related to $\theta_0{}^E$, it follows that $\frac{d\omega^E}{d\eta^E} < 0$ if and only if $n^E > \eta^E$.

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